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Quantitative seismic geomorphology of a confined channel complex, southern Atwater fold belt, Gulf of Mexico, U.S.A.

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Quantitative seismic geomorphology of a confined channel complex, southern Atwater fold belt, Gulf of Mexico, U.S.A.

by

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Abstract

Quantitative seismic geomorphology of a confined channel complex, southern Atwater fold belt, Gulf of Mexico, U.S.A.

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The structures along the Atwater Fold belt form important deep-water hydrocarbon traps in the northern Gulf of Mexico. The purpose of this study is to map and quantify the morphology, sedimentology and architecture of Plio-Pleistocene basin floor fan systems outboard of the Poseidon Minibasin, located along the Atwater deep-water fold belt (mid-Miocene to Pliocene), and apply that information to determine the temporal and spatial nature of the fill and its implications as a reservoir analog. The data set includes ~2200 km sq. of 3D seismic data, along with information from several wells. Wireline logs show the Tertiary age deposits outboard of the Sigsbee Escarpment to be several hundred feet thick, sharp-based, dominantly coarse-grained (sandy) but fining up

cycles composed of sandy basin floor fans, mass transport complexes and leveed channels developed in a confined setting within deep-water “valleys.”

The largest valley formed in five main stages: initiating from narrow channel incision, widening through lateral incision and sidewall slumping, straightening, and finally flooding and infilling. The valley system is ~20,000 feet across and ~ 1,400 feet deep, with what look like well-developed levees ranging from 700 to 1300 feet at their thickest point extending ~19000 feet away from the channel. This system is underlain by a ~700 foot thick mass transport complex and overlain by younger, low sinuosity leveed channel systems. Both of these systems appear to have been sourced by large submarine drainages, originating from a shelf edge sediment source system to feed the rugose slope with deep-water channel pathways uninhibited by salt wall inflation at the time of valley deposition.

Major phases of salt thrusting along the southern edge of the Atwater were contemporaneous with the formation of these large, through-going valley system, which appear to be associated with the period of sheet thickening and development of monoclinal basinward dip related to rafted mini-basin docking.

Well log signatures show evidence for armored clay drapes along the valley margins as well as a flattening of lateral accretion packages toward the distal end of the system. The flattening of these packages seems to signal proximity to the fan terminus, which would serve as an important indicator of spatial extent of plays in deep-water.

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Introduction

Deepwater confined channel systems have been described by numerous authors in both modern and ancient strata, in varying tectonic setting, along offshore margins all over the world (Flood and Damuth 1987, Klauke and Hess, 1996). Confined channels are defined by Posamentier and Kolla (2003) as channels whose areal extent is restricted to its erosional container and to a smaller extent its own constructive levees. Confined channel fills form some of the largest hydrocarbon fields in the world, including in areas of the West Africa margin (Abreau, at al. 2003, Navarre et al. 2002) as well as in the U.S.A. Gulf of Mexico (Roberts and Compani 1996, Lee et al. 1996, Bramlett and Craig 2002). In addition, they form major conduits for the movement of reservoir quality sands into ultradeep-water locations (Posamentier and Kolla 2003, Prather 2000, Gardner and Borer 2000, Beaubouef et al. 1999).

Although their presence can be a critical factor in proving the viability of more distal deep sea fan reservoir deposits, production and development of these features themselves often confound efforts. Draping clays, fine-grained levees, sandy accretionary packages and canyon/valley terminal fan deposits may occur together within a very small area. Recognizing the key components, understanding the formation and being able to map the distribution of facies are key components to safely, successfully and economically producing these reservoirs.

Outcrop studies provide numerous sub-seismic details on these complex rock systems (Beaubouef 2004; Walker 1975), but recognition criteria for interpreting the presence of those details in seismic of any frequency is often lacking. Even when authors attempt to establish such criteria (Stewart et al. 2008), often the two-dimensional nature of outcrops and lack of spatial density of observations render such criteria of very limited use.

The problem of data resolution in seismic is another significant barrier to bridging outcrop and seismic studies. Typical deep-water seismic data may be 65hz dominant frequency, leading to an ability to resolve approximately 14 meters in strata. As Abreu et al (2003) showed in a study comparing the Solitario Deep-water Channel outcrops in southern Spain with the Tertiary-age Dalia Green Deep-water Channel deposits in offshore west Africa, such seismic would most likely fail to image structures on the order of 25-40 meters in height. Therefore, a hierarchical framework approach to seismic analysis of these types of features may lay the groundwork for inferring smaller-scale architecture in static models where such details, often critical to flow behavior, are beyond the resolution of conventional exploration seismic.

Finally, to truly understand the role that these features play as sediment fairways in tectonically complex margins such as Brazil, West Africa or the Gulf of Mexico, we need to examine their occurrence within the context of tectonic history. In the Gulf of Mexico, the dynamic linkages between the abyssal basin floor and the more proximal mini-basin riddled slope are crucial factors to consider when studying the evolution of these deepwater valley systems in the manner in which they either store or bypass sediment.

Research Problem

The goals of this study are multi-fold. The first goal of this study is to investigate the nature and architecture of an extremely well imaged, large confined channel system in the distal Sigsbee escarpment to assist in prediction of lithology, quality, continuity and connectivity of deep-water confined channel reservoirs in areas where imagining is more suspect. The Plio-Pleiestocene large-scale channel levee system in the Mad Dog area provides a high-resolution seismic example of such a system.

A second goal of the study is to bridge the scales between seismic and outcrop. The distribution of elements within a large-scale deep-water channel levee system, as well as their morphology, is affected by gradient and varies with proximity to the terminus. We want to take advantage of the 3D data coverage in this study to look at Confined Channel fill architectures as they vary spatially from more proximal areas to more distal areas out in the front of the modern escarpment.

The third objective of this study is to utilize the seismic geomorphologic history of inboard and outboard stratigraphy to interrogate models of structural evolution and timing in the distal Sigsbee Salt province, and challenge how that evolution has influenced the nature of such large confined channel feeders. Due to post-confined valley development growth of the salt body, there is a large offset between time-equivalent

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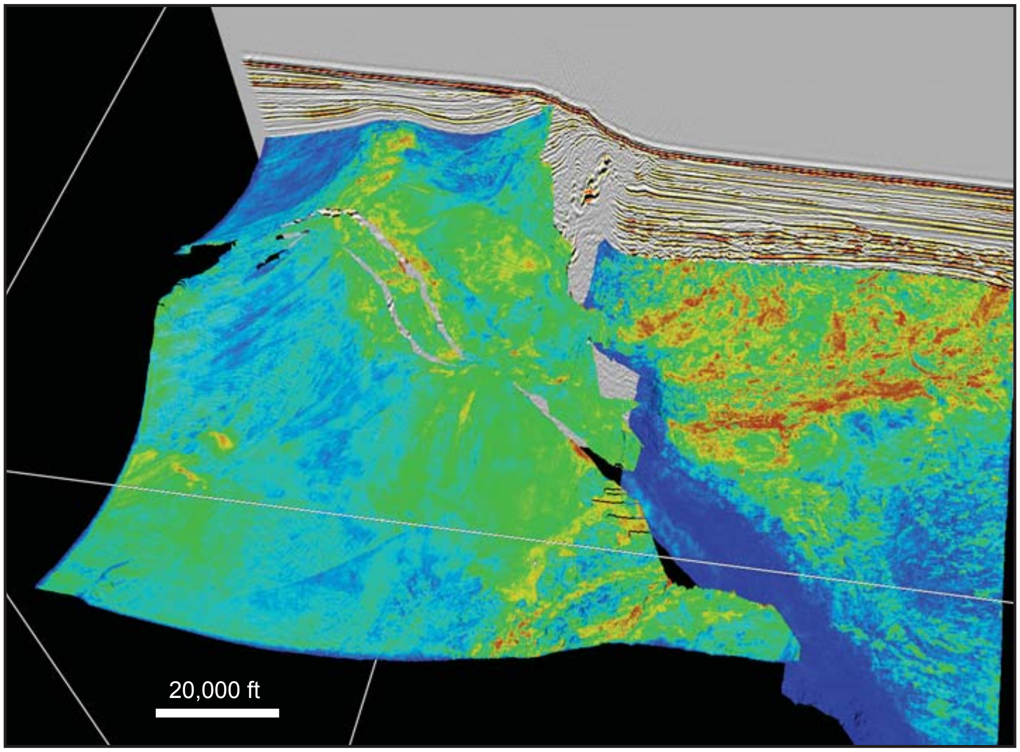

Courtesy of BP and partners

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Figure 1. Time-equivalent horizons in the minibasin and outboard area. Offset of these horizons due to emplacement of the Sigsbee Salt. At the time of deposition (roughly Plio-Pleistocene), these two domains were continuous. Warm colors indicate high amplitude. Cool colors indicate low amplitude.

strata in the inboard and outboard regions (Figure 1). The nature of these confined channel feeders in part reflects the history of structural movements in the salt canopy around them. It has been proposed that the southern flank of the mini-basin inflated in early Pliocene (Hudec, pers. Comm. 2006). The continuity or discontinuity of linkages between northern and southern portions of the Mad Dog study area should reflect such connection or isolation between the canopy and the abyssal plain. By looking more closely at the seismic geomorphology of the outboard area and determining timing of linked shelf-slope deposition, timing of escarpment emplacement and inflation can be better constrained.

Objectives

To achieve the broader goals discussed in the previous paragraphs, several more specific objectives were defined. These include:

- Map and quantify the morphology, sedimentology and architecture of Plio-Pleistocene confined channel system (a deep-water valley) in the Mad Dog area.
- To interpret and describe the surfaces and facies associated with confined channels and spatial changes that occur in them over time.
- To attempt to apply those observations made on confined channel systems in outcrop to seismic scale-defined confined channels in order to link the seismic and outcrop scales.
- Define the temporal and spatial nature of channel incision and fill in this valley to provide insight into the linkages between proximal minibasin and distal abyssal plain across the significant boundary that is the Sigsbee Salt.
- Integrate well log data to better understand the system as a reservoir analog, including relationships between sands and shales and potential for connectivity of sands.
- To link channel evolution and behavior to salt tectonic history in order to better constrain timing of salt emplacement.

Terminology

The terms incised valley, valley, canyon and channel are often used in literature with little thought to what they actually mean historically, the implications for using them in a submarine versus a subaerial setting, or the overall implications for associated facies. These are terms that were originally coined in subaerial environments. In historical geomorphologic literature, an incised valley is defined as a “fluvially-eroded, elongate topographic low that is typically larger than a single channel form, and is characterized by an abrupt seaward shift of depositional facies across a regionally mappable sequence boundary at its base” (Zaitlin et al. 1994). The term valley is typically used to describe the “path of a channel reach as a straight line between two points” (Flood and Damuth 1987), essentially a construct used to measure aspects of a channel system. Canyon is defined as “long, deep, relatively narrow steep-sided valley confined between lofty and precipitous walls in a plateau or mountainous area, often with a stream at the bottom” (Jackson 1997) and a channel is defined as “ an erosional feature “that may be meandering and branching and is part of an integrated transport system (Pettijohn and Potter 1964). Although fluvially generated and deep-water generated morphologic features do share several apparent similarities to deep-water morphologic features (Peakall et al. 2000) one must utilize caution in the use of these terms lest one thing the use of the term implies certain processes or deposits in common with similar subaerial deposits.

One definition scheme for the terms valley, canyon and channel used in deep-water deposits relies on the location of the feature within the deepwater setting. For example, mid-slope channels are defined by Beaubouef et al. (1999) as the upslope part of a basin floor fan. According to this scheme, channel formation is typically associated with the formation of canyons on the slope and the incision of fluvial valleys into the shelf. This scheme is useful in that element morphology and distribution is partially dependent on position within the overall system (Figure 2).

Mutti (1977) defines a channel as a long-term conduit through which sediment is transported downslope. Channels, channel complexes, channel complex sets, etc., are traditionally classified by time scale. An individual channel is the result of a single cycle of erosion, infilling, and abandonment (Sprague et al., 2002), and typically occurs on the 5^{th} order time scale (Navarre et al. 2002). The channel, or "channel storey" is defined by the surfaces at its base and cap. The base of the "channel storey" is a sharp erosional surface and the top surface is composed of capping shales. It is important to note that these shales are a major control in reservoir compartmentalization (Navarre et al. 2002).

Channels may occur by themselves in the stratigraphic record, or they may be stacked or amalgamated (Figure 3). These complex channel systems may appear as leveed channels meandering within a larger leveed channel system in seismic (Posamentier and Kolla 2003). A channel complex is a 4^{th} order stratigraphic unit formed by stacked individual channel stories. Two or more channel complexes, each bounded by

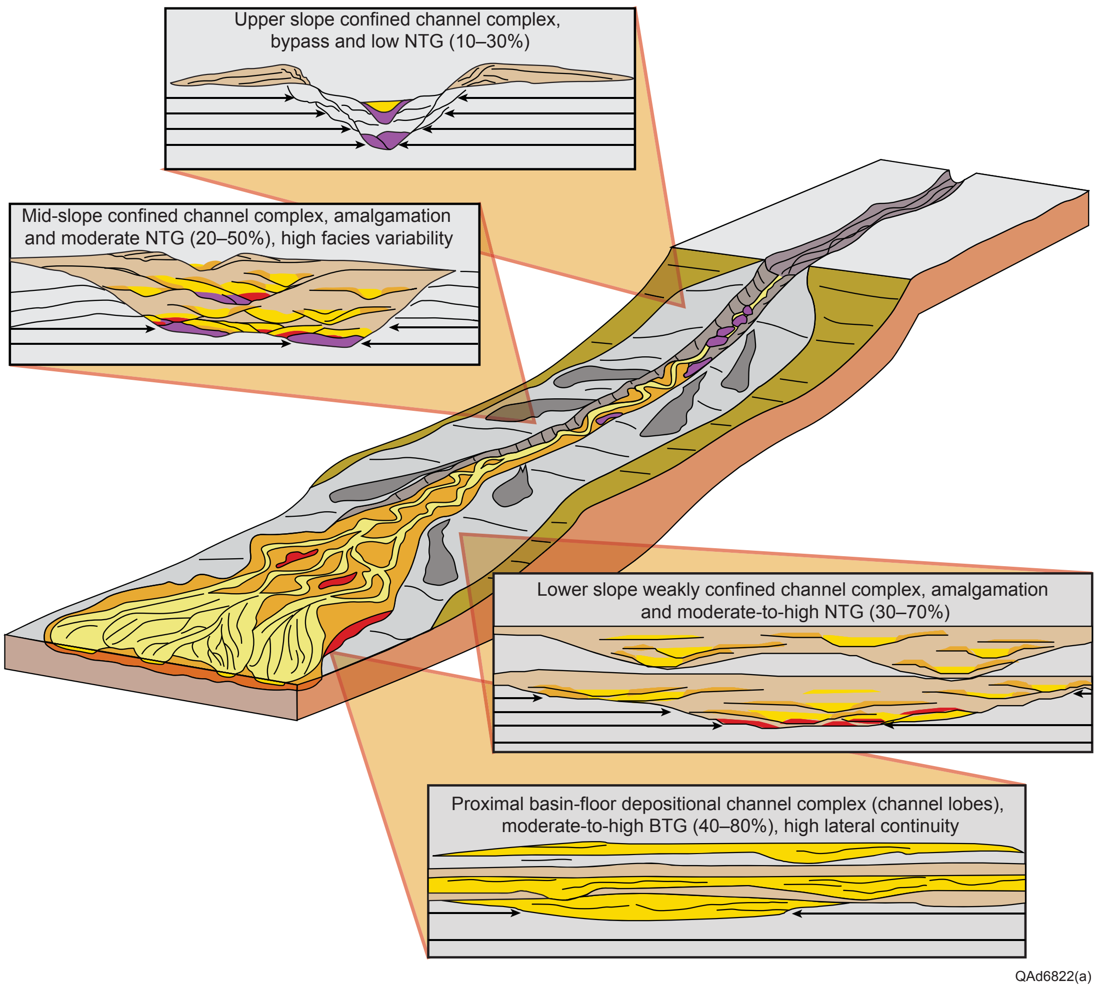

Figure 2. Deep water confined channel depositional model. The distribution and morphology of elements within a large scale deep water confined valley system are affected by gradient and vary with proximity to the terminus. Net sand increases downdip as the slope of the margins of the channel bodies decreases. As the gradient decreases down the fan, slopes of interior channel architectures shallow out and channels become unconfined, eventually transitioning to basin floor fans.

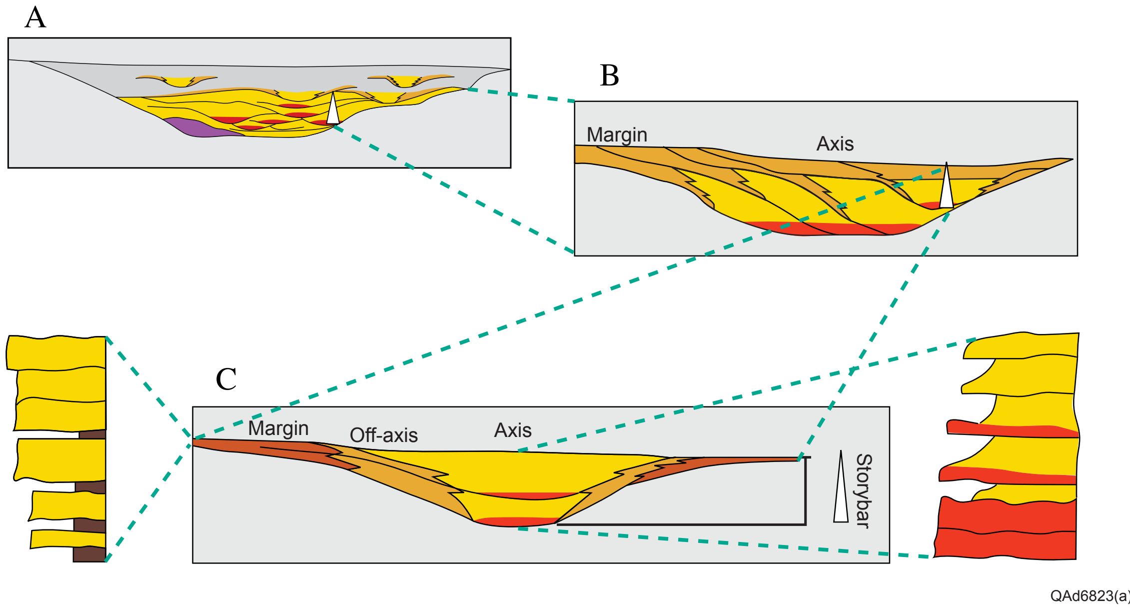

Figure 3. Stratigraphic hierarchy for a confined channel complex. A. Stacked channel complex. B. Channel Story C. Individual Channel Phase. Individual channel phases exhibit a fining upward morphology with sharp erosional bases. A channel complex will contain several of these fining upward units.

a regression at the base and a transgression at the top form a channel complex set (Abreau et al. 2003).

Channels typically occur in association with related facies. A channel-levee system includes several elements: channels with potentially complex interior architecture, levees, overbank deposits and distal splays (Wood and Mize-Spansky 2009). These are referred to as Type III fans according to Mutti's classification scheme (1985). The distinguishing feature of these systems is the presence of levees. Levees are "elevated berms that parallel either side of a channel and aid in keeping the flow of water and sediment within the channel" (Wood and Mize-Spansky 2009). They form and grow as water with suspended sediments spill over the edge of the channelform during times of increased flow. Energy decreases outside of the confined channel, and sediments are dropped, depositing a thin layer of usually fine-grained sediments (silt, clay, and fine sand) on top of the previous levee (Galloway and Hobday, 1996). The general morphologic character of levees consists of two wedges on either side of the channel that thin away from the well-developed channelform (Wood and Mize-Spansky 2009). In seismic, these levees typically have the "gullwing" signature (Kendrick, 2000). The process by which levees form is roughly the same in all environments in which they form: marine and fresh water, subaerial and submarine, and shallow marine and deep marine. Several factors can influence the levee thickness and extent in deep-marine settings, including sediment type, sediment volume, sea-floor and channel-floor (Wood and Mize-Spansky 2009).

When these channel-levee systems are confined to the depression they erode into the seafloor, they are said to be valley-confined, leveed-channel systems (Posamentier and Kolla 2003). For the purpose of this study, these systems will be referred to simply as "confined channels." Confined channels are produced by the erosion and downcutting of older sediments by turbidity currents, and are therefore only present in subaerial settings (Abreau et al. 2003). Abreau et al. (2003) differentiate between confined channels contained within previously deposited sediments as well as their own levees, and those contained solely with constructive levees, but for the purpose of this thesis, there is no distinction. Further downdip, the fill tends to spread beyond the well-defined channel margins and sedimentation is not restricted to the erosional container. There is less likelihood for nesting and amalgamation in these settings (Posamentier and Kolla 2003). These channelforms will be referred to as "unconfined channels."

The above classification is very similar to descriptions of subarial river systems, but there are distinctions to be made. The morphology of both subaerial rivers and underwater channels are affected by gradient, flow discharge and grain size, among other factors (Klaucke and Hess 1996). While at first glance, the morphology of fluvial channels and marine turbidite channels may appear similar, even identical, very distinct processes form each. Major differences include effective gravity and friction at the upper boundary of flow, which are much stronger factors in subaerial settings due to the smaller differences in density between the flow and surrounding media (Peakall et al. 2000). Because of the very different circumstances under which each deposit is formed, it is simple to conclude that there would be at least subtle differences between the morphologic characters of the deposits. The same type of distinctions should be drawn between subaerial and subaqueous valley systems.

Valleys and canyons form by similar processes of erosion and due to similar forcing as channels, but the scale is very different. When slope canyons and valleys are infilled, they are typically filled with the above-described channels and channel complexes (Flood and Damuth 1987). For the purposes of this study, a valley is the container for a channel or channel complex. It is incised and later infilled with channel deposits.

Canyons are distinguished from channels by several criteria. Canyons cut into the bedrock and sediments of the shelf and slope. They normally have a V-shape in profile and typically have a steeper gradient than their associated channels. Canyons are zones of sediment bypass and little deposition occurs within them until they become inactive (Normark and Carlson 2003). A key difference is the absence of levee morphology commonly found along channels (Shepard 1963). They typically can be found in the upper slope and connect directly to the shelf-edge (Wynn et al. 2007). The erosion of large canyons in slope and shelf settings requires long periods of stability. They may form in active salt provinces but will eventually be healed due to salt inflation (Brown and Fisher 1980 and Lee et al. 1996).

On the other end of the scale spectrum, the interior surfaces of the channel complex can disclose much about the timing and spatial distribution of channel elements throughout the system's evolution. At least two classes of accretionary macroforms have been identified in confined channel fills; Lateral Accretional Forms, or LAPs, and Mid-Channel Accretionary forms (MAPs)(Figure 4). Understanding the nature of these internal architectural forms within confined channels could significantly improve our understanding of the nature of confined channel fills and how they might perform in the subsurface under flow conditions. Laterally accreting forms imply that successive flows laid down-dipping units of strata that accreted toward the axis of the channel form, instead of in the upcurrent direction. The authors envision this lateral accretion pattern to reflect deposition along the outside bend of a sinuous channel form. As turbidity currents impinged on the channel bank, tractional deposits were plastered against the outer part of the bank, leaving dipping beds that parallel the channel bank/floor. This view is consistent with the description of flow stripping and outer channel margin sand lens deposition presented in Clark and Pickering (1996). Medial Accretion, also known as Straight Course/Gentle Upcurrent Accretion or Backstepping Inclined Sandy Macroform accretion, occurs as fans backstep and translate updip due to changes in channel gradient (Pickering et al., 2001). These sub-valley scale features are an important target of research for this study.

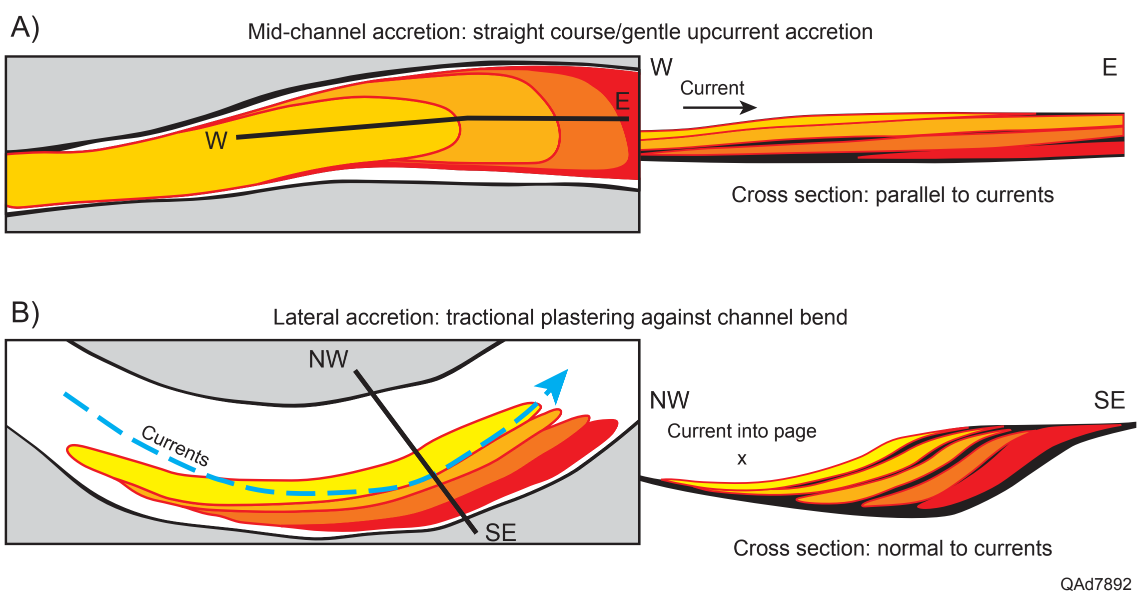

Figure 4. MAP and LAP formation. Mapview and downdip view of Mid-channel accretion packages and lateral accretion packages. A) Straight Course/Gentle Upcurrent Accretion occurs as fans backstep and translate updip. B) Lateral accretion occurs as tubidity flows plaster sediments against the sides of the channel and grow toward the axis of the system. (After written comm. Jeanette 2004)

Geologic Setting

The Gulf of Mexico basin was formed as the South American, African and North American continents rifted apart, breaking up the supercontinent of Pangaea. Rifting began in Late Triassic, a period characterized by deposition of red beds and volcanics. Marine encroachment into the modern Gulf of Mexico did not occur until Late Jurassic, although there were some marine facies associated with local Pacific embayments during Middle Jurassic time. It was during this initial flooding event that extensive, thick salt deposits were formed. The distribution and thickness of these salt deposits varied with local subsidence rates (Salvador 1987).

Loading of Mesozoic and Cenozoic sediments, caused by the advance of deltaic wedges onto the tabular salt sheets, caused salt mobilization. Later deposition and continued loading initiated formation of the complex salt structures that now define the northwestern Gulf of Mexico (Prather 2000).

During the Plio-Pleistocene, the depocenter within the Gulf of Mexico shifted southwestward to the shelf edge south of the modern Texas-Louisiana border. Normal deltaic progradation cycles continued throughout this time period, with a few differences. The main changes in depositional processes during Late Pliocene through Pleistocene are related to responses to glaciation cycles. Changes in timing and response of deposition to glacio-eustatic cycles and increased sediment supply related to glaciation define Plio-

Pleistocene-age deposition. Established Pleistocene-age paleogeography puts the Mad Dog on the western edge of the Mississippi canyon/fan system (Galloway et al. 1991)(Figure 5).

The Mad Dog area is located in the southeastern corner of the Green Canyon Block of the Gulf of Mexico along the modern day Sigsbee Escarpment (Figure 6). There are three main modern day provinces within the Mad Dog: the mini-basin province, the escarpment and the outboard region (Figure 7). The Sigsbee Salt sheet occupies a large part of the middle slope and is derived from Jurassic autochthonous salt deposits (Grando and McClay, 2004). The mobile salt substrate creates a “pock-marked” pattern of mini-basins throughout the area inboard of the Sigsbee Escarpment, including the Poseidon and Mad Dog mini-basins of the study area. The Sigsbee Escarpment is the seafloor expression of the downdip end of the Gulf of Mexico salt sheet, and is expressed as a sudden and steep 600 to 700 foot drop in the seafloor, with a slope of greater than 20° (Orange et al. 2004). Basinward of the Sigsbee is the relatively flat, featureless abyssal plane.

The mini-basins present in the study area are thought to have been rafted from distances north. Such “rafts” are defined by Jackson and Talbot (1991) as “fault blocks of allochthonous overburden that have separated so that they no longer rest on their original footwalls, and lie entirely on a decollement, which typically consists of salt.” The Poseidon minibasin is proposed to have been rafted approximately 28 miles from the north based largely on a thick, repeated Miocene section in the inboard region (Hudec, pers. Comm. 2006)(Figures 8-9). Hudec and Jackson (2006) suggest that subsalt overpressure is the cause of thrust advance in the case of the Sigsbee Salt. The method of salt sheet advance matches the “salt glacier” or “tank tread” models most closely (Orange et al., 2004). In this model, the salt is moving through gravitational forcing and the suprasalt strata are not being deformed.

From the regional perspective, the study area is located at the southern end of the Atwater Fold Belt that was formed due to two major contractional events. Early folds formed during Upper Jurassic through Cretaceous due to gravity gliding on a basinward-dipping basal salt detachment. Later, larger-scale fold growth occurred due to gravity spreading as a result of continued progradation of clastic wedges (Rowan et al., 2000). The Frampton Anticline occurs in the study area, just outboard of the escarpment. This large fold structure formed during a later phase of contraction caused by the advancing allochthonous salt sheet. The main stage of fold growth on the Frampton structure occurred from Late Miocene through Pliocene time (Grando and McClay 2004). Syn-sedimentary folding on the Frampton structure has lead to a drastically thinned to absent Upper Miocene to Pliocene section (Figure 10).

Water depth in this area is roughly 7000 feet in the outboard. In the Mad Dog, salt thicknesses reach up to 8000 feet just north of the escarpment (Huang et al. 2009).

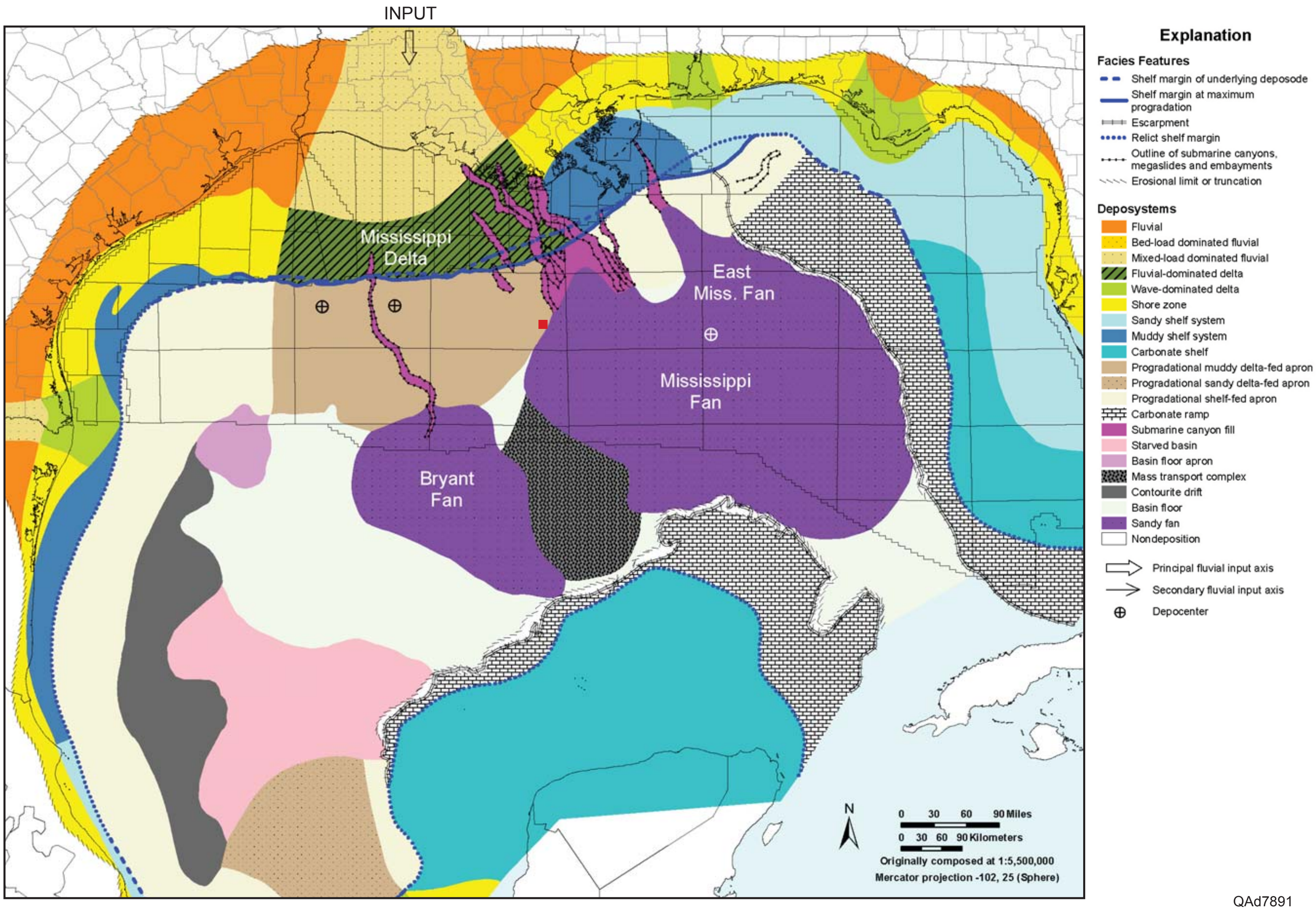

Figure 5. Pleistocene Paleogeographic map showing the location of the Mad Dog (red square) on the western edge of the sandy Mississippi Fan system and just south of a large canyon system that feeds sediment into deep water. Map courtesy of Gulf of Mexico Basin Depositional Synthesis Group at The University of Texas Institute for Geophysics.

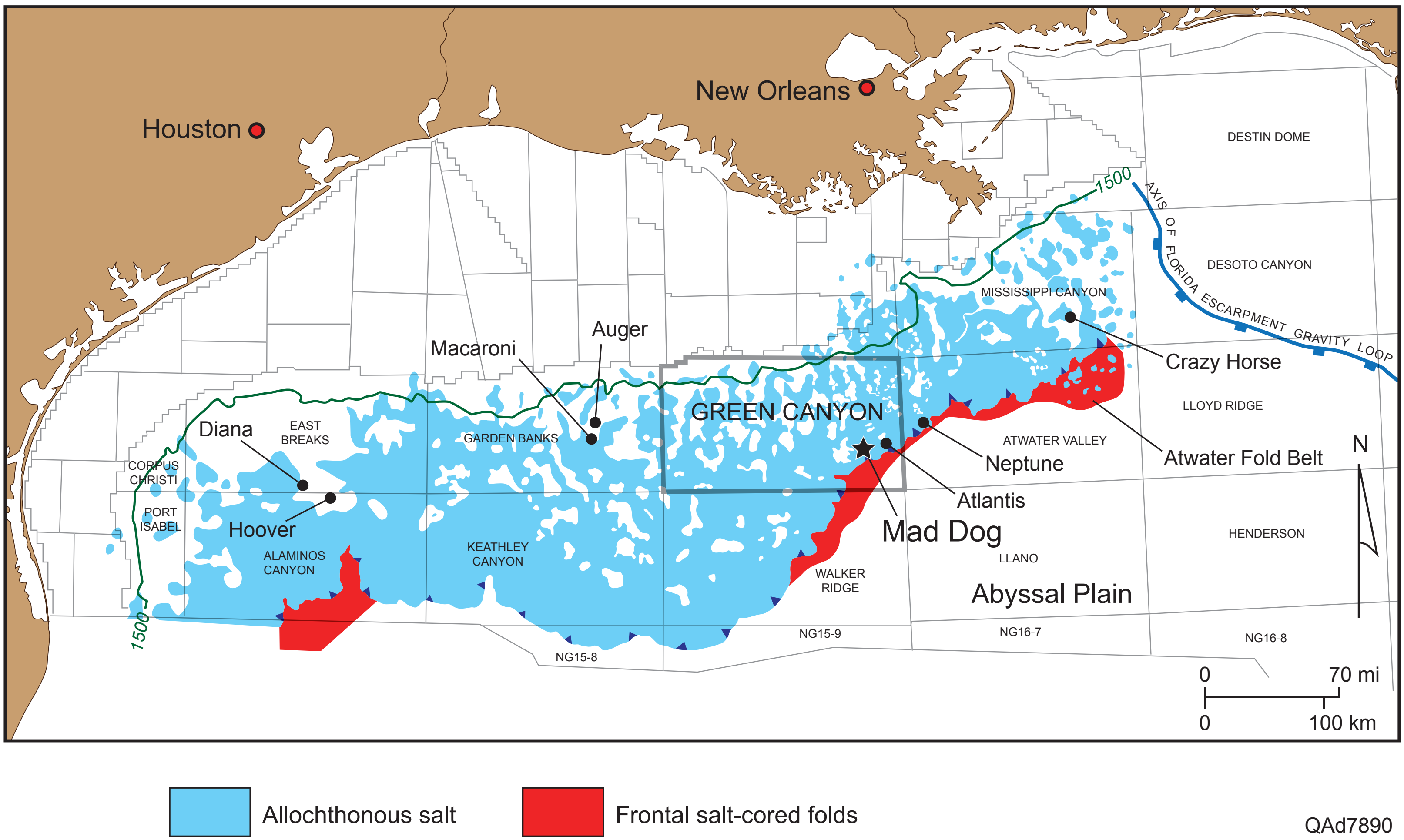

Figure 6. Modern geologic setting. Map of the northern Gulf of Mexico showing modern setting of the Mad Dog area on the southern edge of the regional allochthonous salt sheet. The Mad Dog study area lies in the southeastern corner of the Green Canyon Block, just to the north of the Atwater Fold Belt. (After Hall 2002)

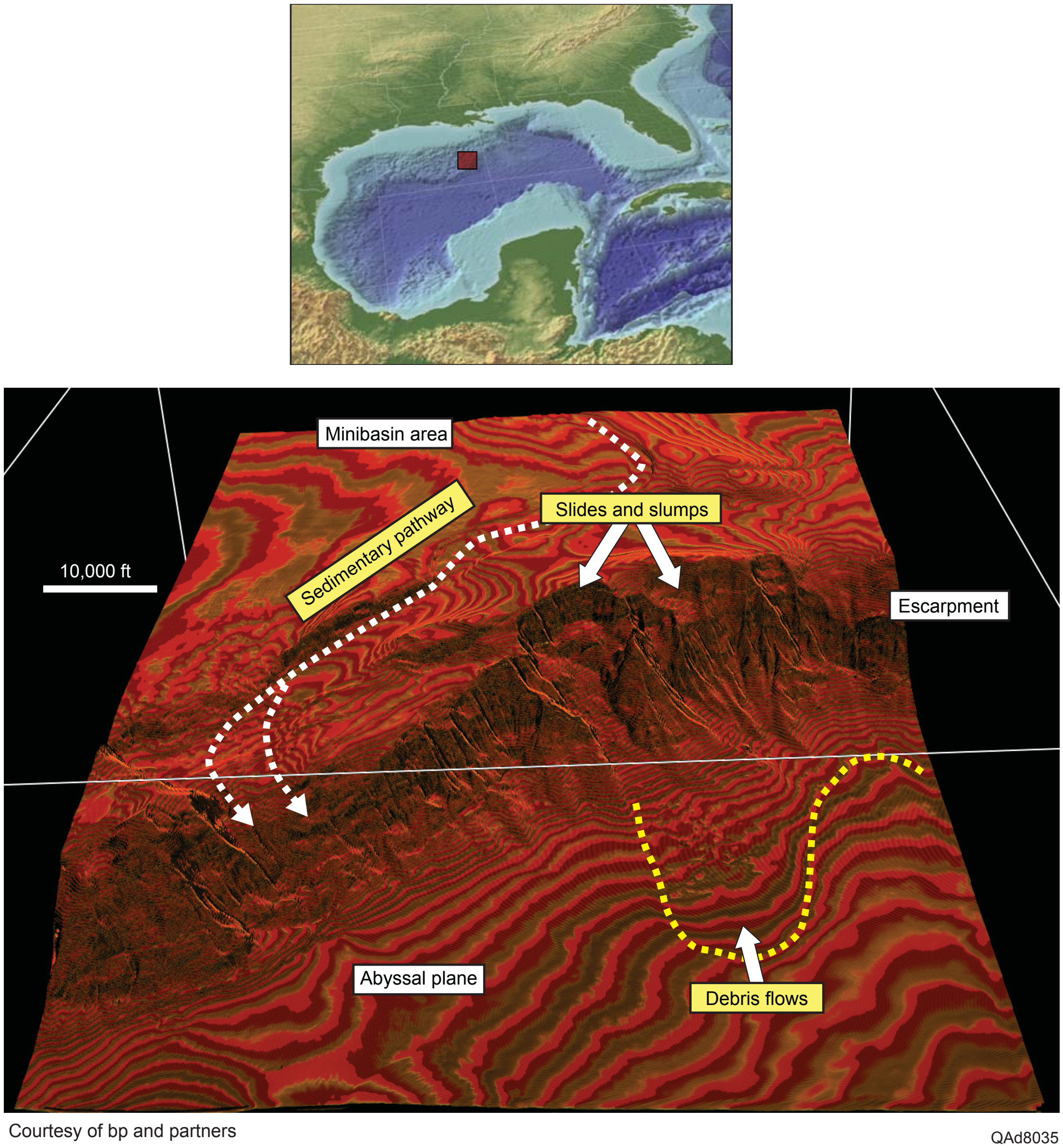

Figure 7. Three distinct provinces on modern seafloor. Within the Mad Dog area, three distinct provinces are distinguishable on the modern seafloor: minibasin (inboard area), escarpment and abyssal plane (outboard area).

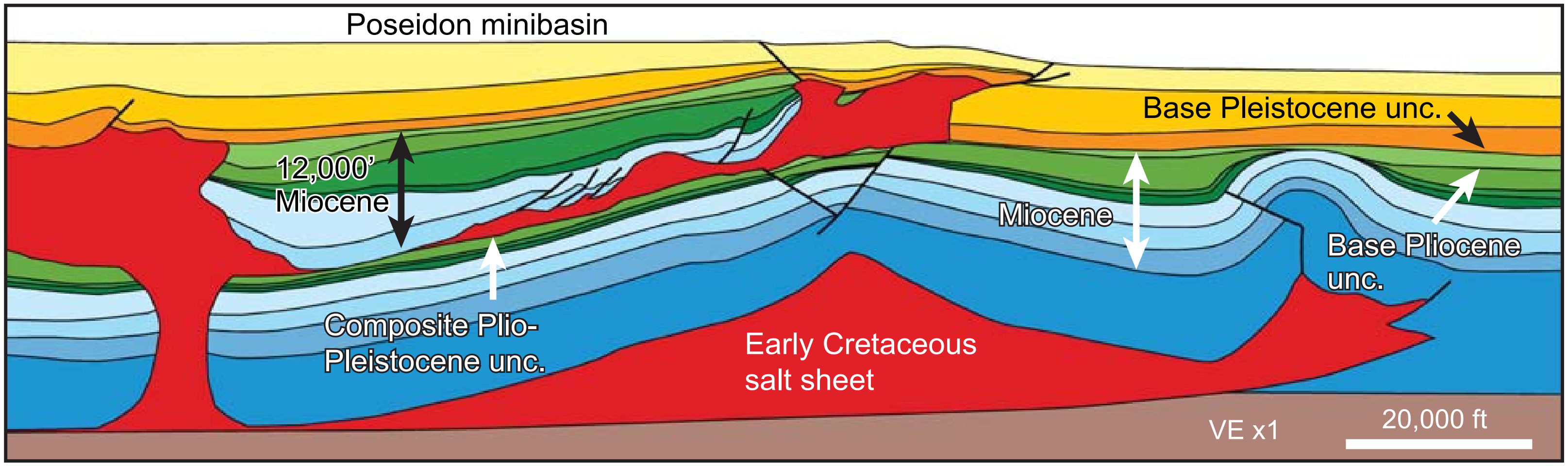

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Figure 8. Structural cross section. Repeated Miocene section is evidence for rafting of minibasin during Teritary. "Docking" of the minibasin is associated with the monoclinal development between the Minibasin and the outboard area. Uplift of the Frampton anticline explains near absence of Pliocene sediments in the outboard area. (After Hudec written comm. 2006)

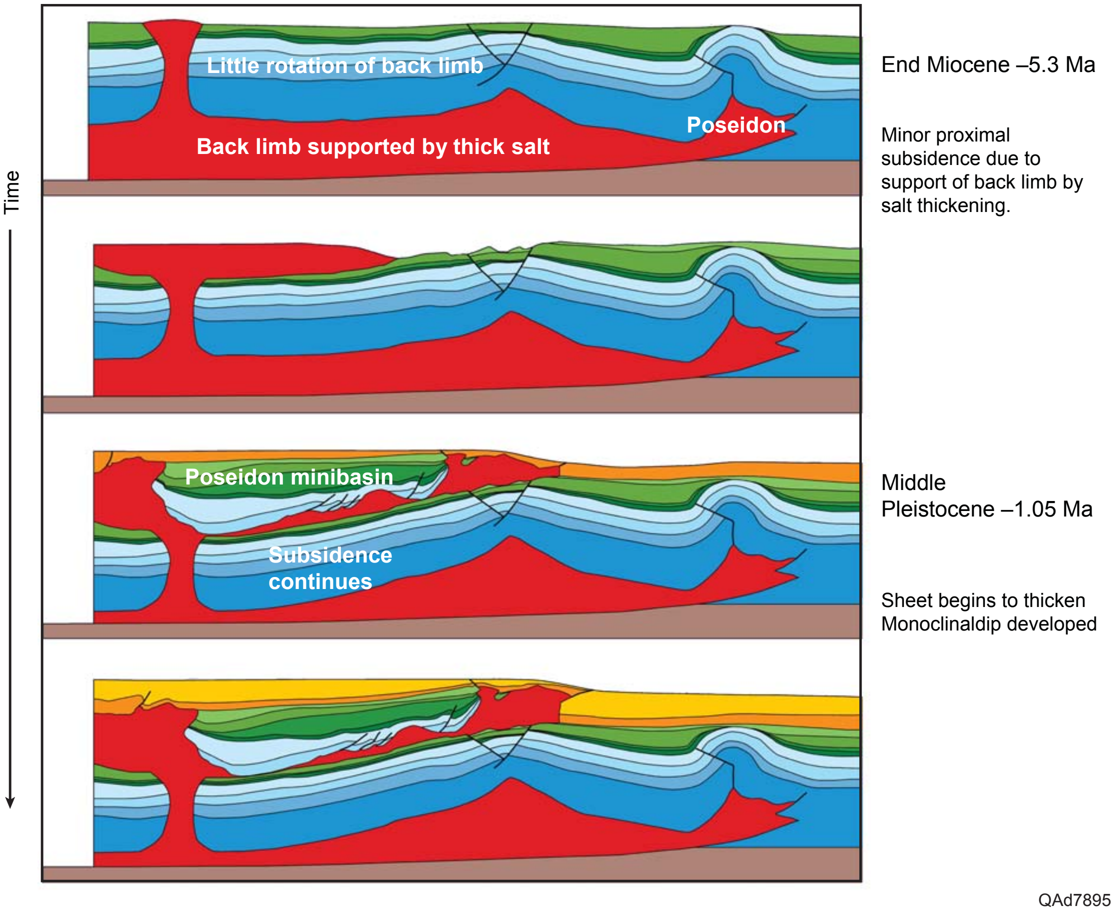

Figure 9. Structural model for evolution of the Poseidon Minibasin. The Poseidon Minibasin was rafted in the early Tertiary from approximately 28 miles north to its present position. It was transported on top of the allochthonous salt body until it came to rest atop the Mad Dog anticline, forming a large monoclinal structure on the seafloor. (After Hudec written comm. 2006)

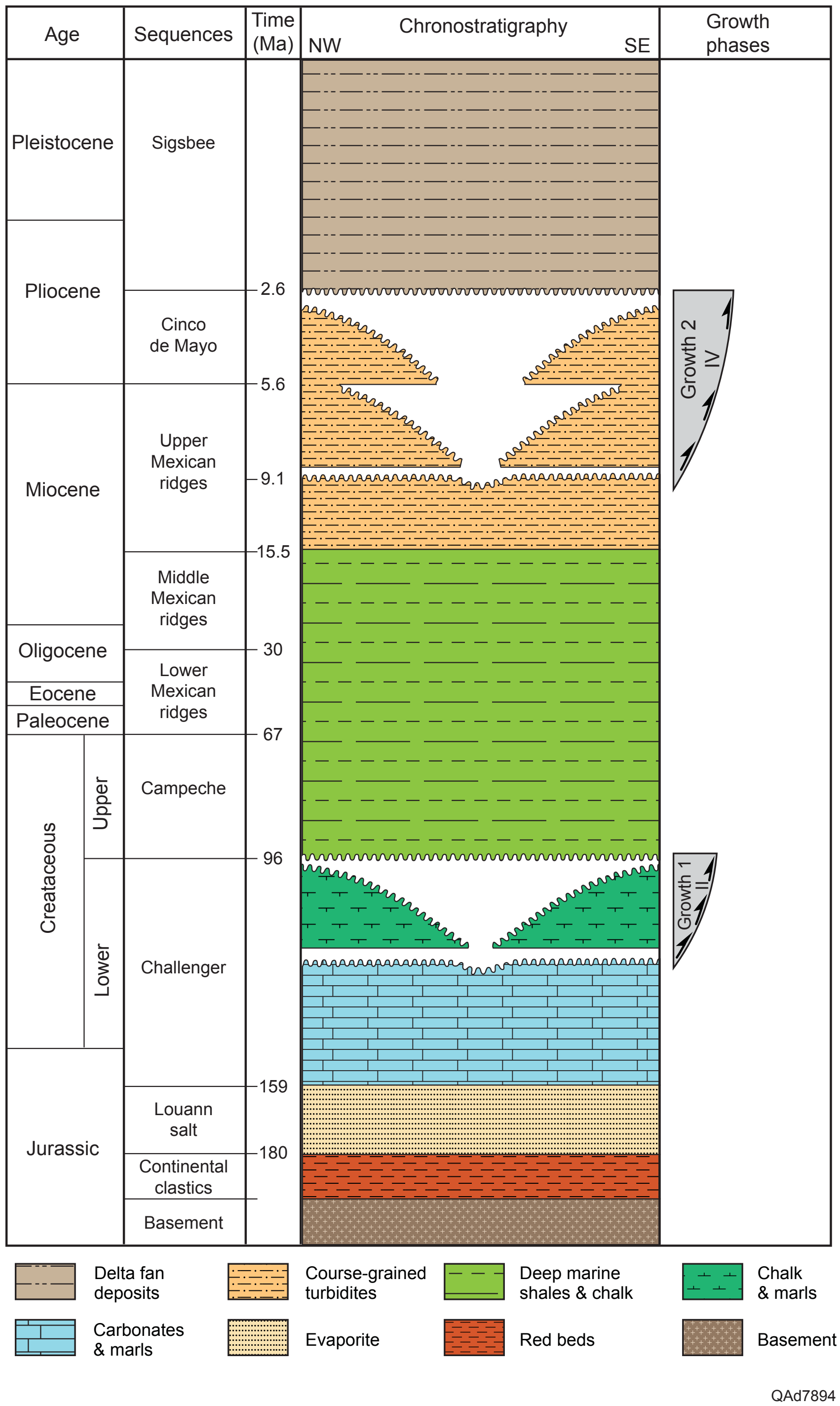

Figure 10. Chronostratigraphic chart of area surrounding the Frampton Anticline illustrating general lithology associated with the evolution of the basin. Wedging of deposits during the Cretaceous and Miocene-Pliocene correspond to the two periods of growth of the fold. For this study, it is important to note the attenuation of Late Miocene and Pliocene sediments due to growth phase 2 of the Frampton Anticline. (After Grando and McClay 2004)

Data and Methodology

The dataset for this study includes approximately 2200 km sq of 3D exploration poststack, depth migrated seismic data. The seismic survey was acquired using 12.5-meter in-line and cross-line spacing (Figure 11). Well data includes six wells which salt penetrate the underlying salt sheet and one well penetration basinward of the allochthonous salt. All wells indicate the presence of several thick cycles of basin-floor fan deposits, leveed channel and mass transport deposits.

Only one well penetrates the deep-water valley system that is the focus of this study, well GC826 1BP2 (Figure 12). Biostratigraphic data in the section is provided by one well, therefore age control is not tightly constrained. Several geotechnical papers have been published on the area, including Orange et al., (2004) and structural studies in the area include Hudec and Jackson (2006).

Extensive mapping by previous workers (Huang et al, 2009, Wei et al., 2009). provide a larger stratigraphic framework for this study. However the focus of this study lies between horizons F15 and F12 of Huang et al. (2009). Several surfaces were mapped bounding a large-scale channel levee-complex in the abyssal plain using the workstation. Finely gridded horizons of the lower bounding surface (jlm_base_channel_complex) of the deep-water valley and the flooding surface (jlm_flooding_surface), which caps it, as well as the base of the fine-grained apron deposits (jlm_base_levees) were mapped, interpolated and smoothed (Figure 13). These surfaces provided the bounding framework

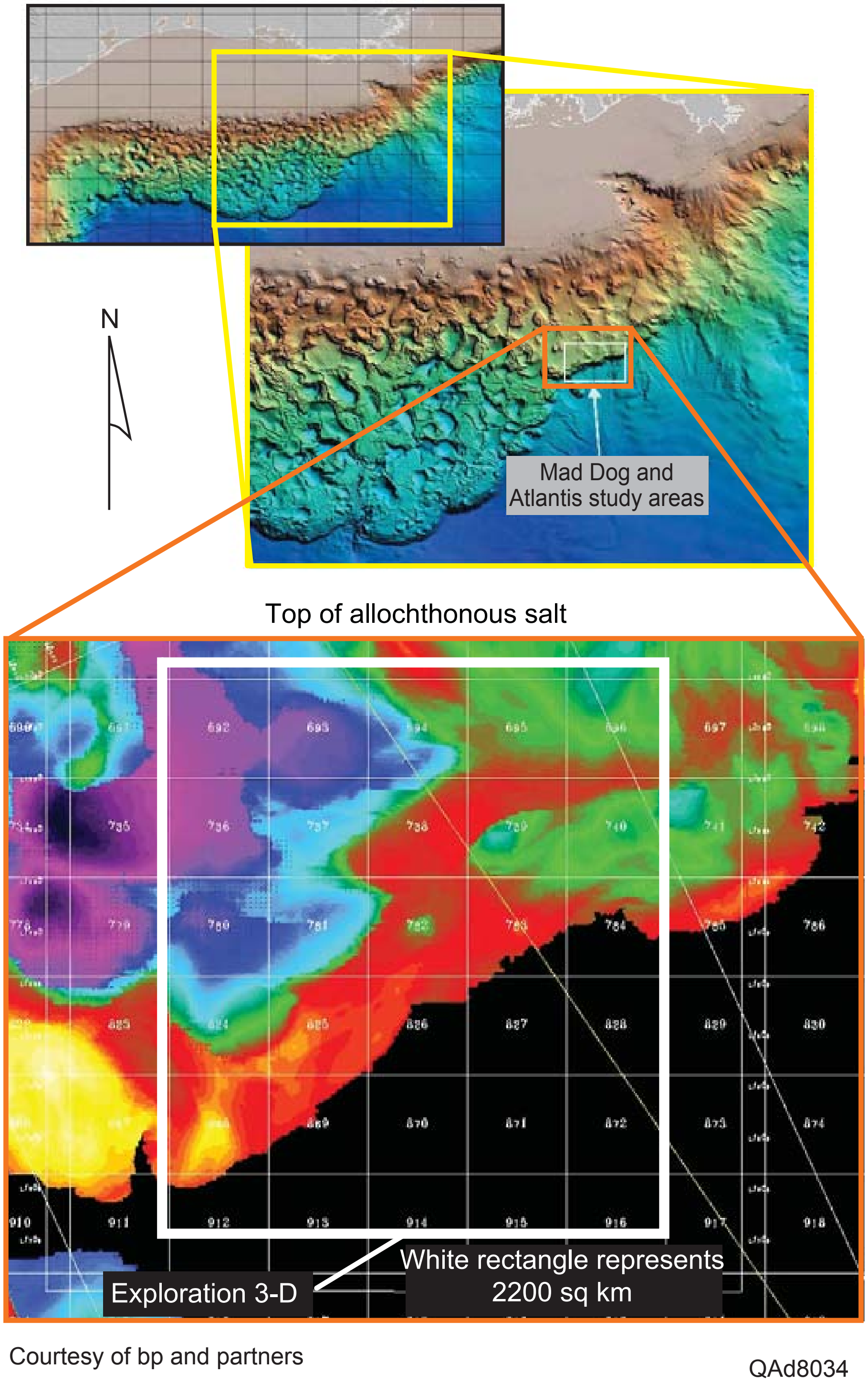

Figure 11. Data extent. The Mad Dog dataset is composed of roughly 2200 km sq 3D poststack, depth migrated seismic data. The seismic survey was acquired using 12.5-meter in-line and cross-line spacing. (After Orange et al. 2004)

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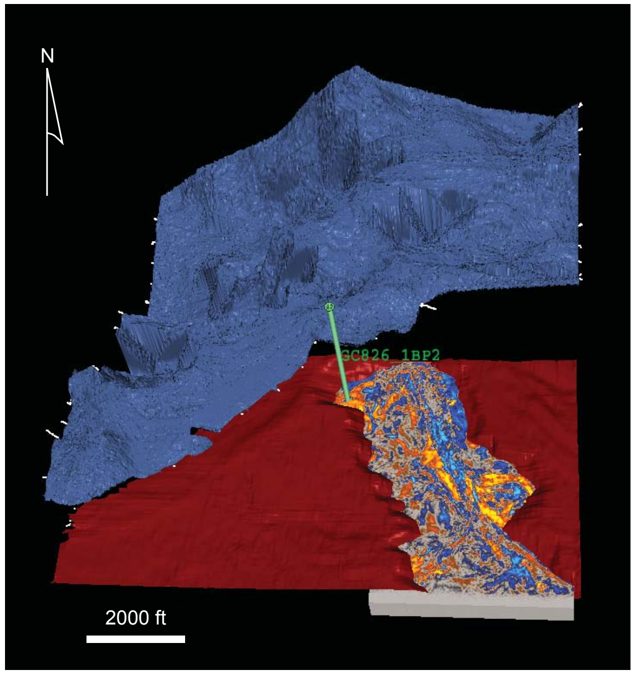

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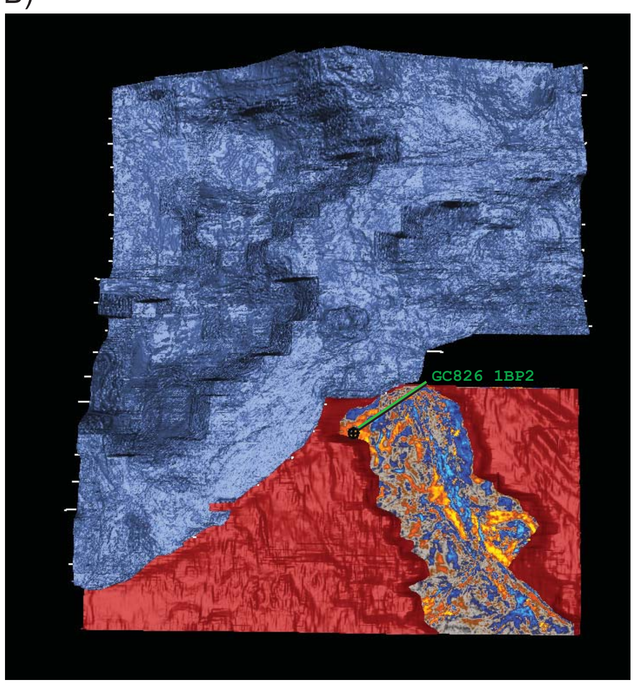

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Figure 12. Well Location. Well GC826 1BP2 is located adjacent to the salt front along the western margin of the deep water incised that is the focus of this study. The red surface represents the master channel surface. The blue surface is the tip of the salt front.

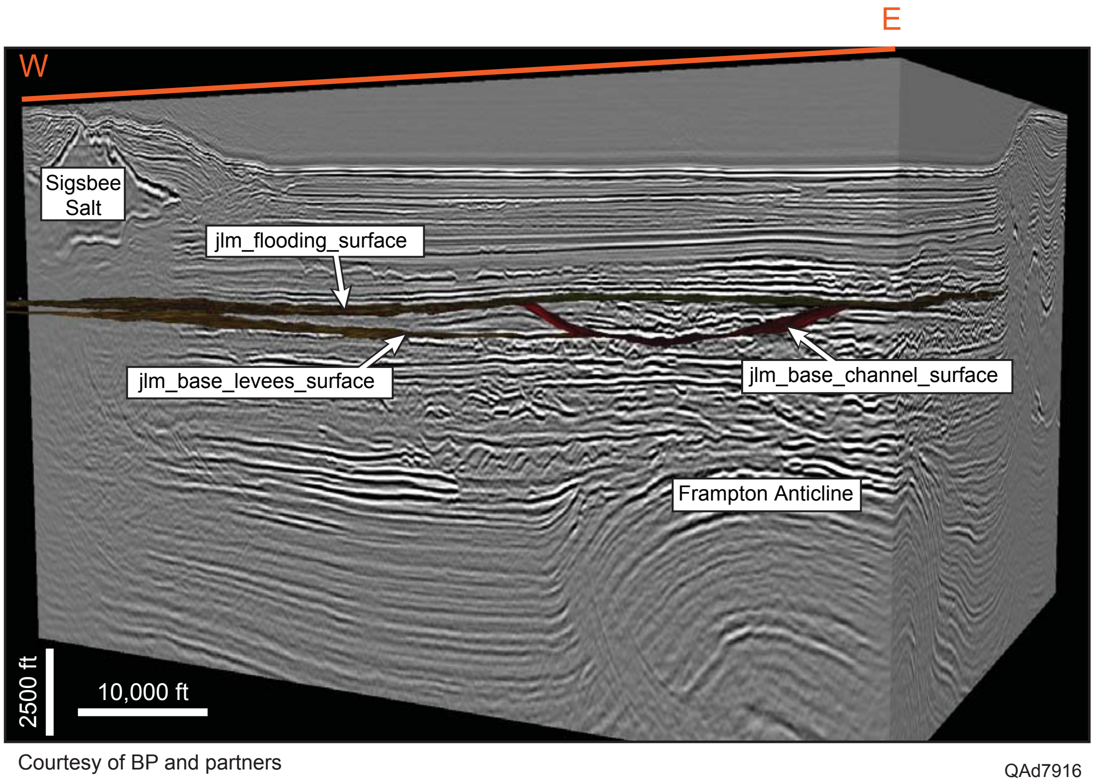
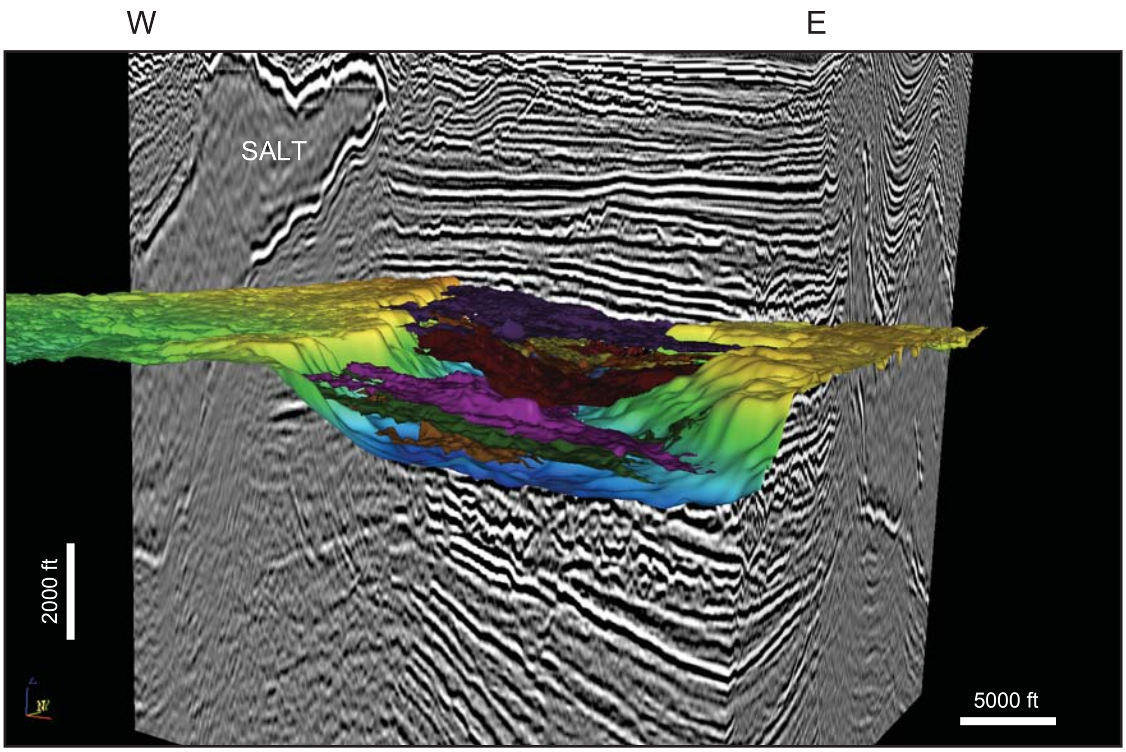


Figure 13. Major surfaces. Seismic volume with clipped channel complex master surfaces showing the location and size of the large channel complex with respect to other major features in the system.

within which to examine the more detailed, seismic scale architecture within the valley. Smaller-scale interior LAP and MAP surfaces were also mapped (jlm_lap1 thru jlm_lap10) (Figure 14).

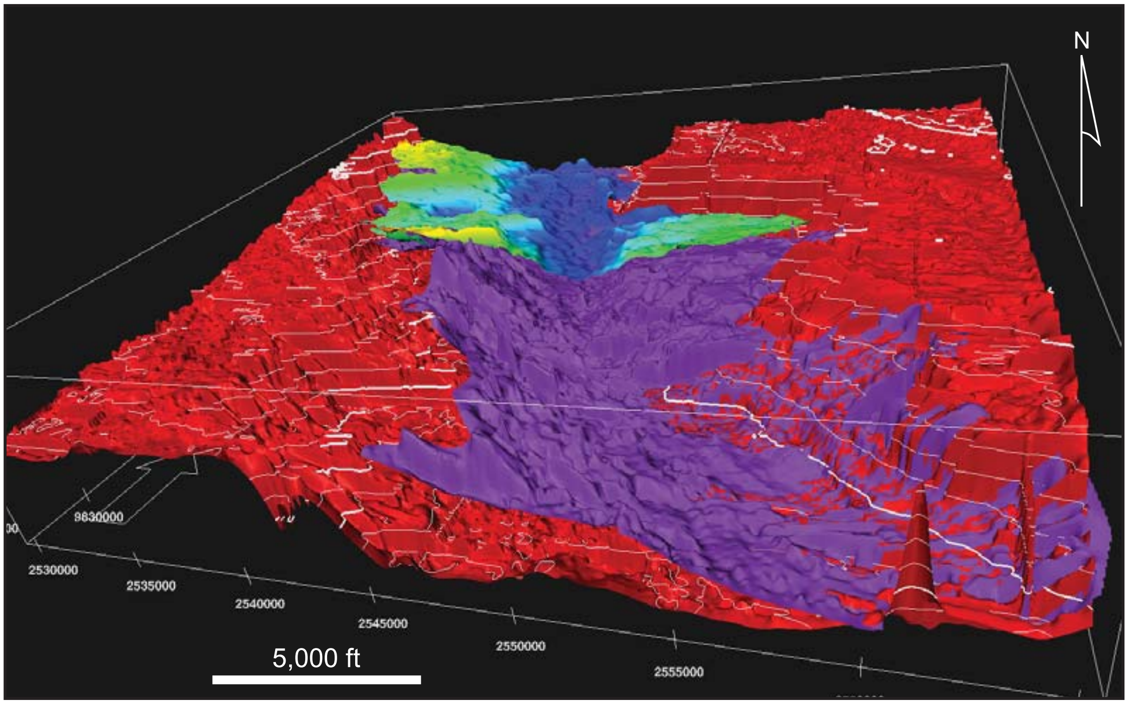
Once generated, horizons were imported into Roxar and converted to surfaces, smoothed and filtered (Figure 15). The surfaces were then imported into Geoprobe, where horizon and interval attribute analysis was done for investigation of the seismic morphologic elements. Stratal slicing, also known as proportional slicing (which divides the thickness of the interval at any given point by the number of slices, creating surfaces that are uniformly spaced between two non-parallel surfaces) (Huang et al. 2009). was performed between the base and top of the apron deposits (Horizons jlm_flooding_surface and jlm_base_levees, respectively) to examine the morphologic make up of the finer-grained overbank deposits. The single well had a full suite of logs, as well as paleontologic data and provided ground truth on the lithology of valley fill intervals. Isopach maps provided a documentation of the temporal and spatial variations of thicknesses of fill within the valley. Mapped horizons, log-based lithologic analysis and subsequent analysis of inter-horizon stratal architecture and morphology, provided the basis for building a history of valley evolution and integration of that history with previous structural evolution models. The one well that penetrates the valley was integrated with the seismic data to provide insights on the character of the northern margin of the valley's fill.



Courtesy of BP and partners

QAd7898

Figure 14. Interior surfaces. Base of channel complex and interior accretionary packages. Channel fill has a complex geometry that varies laterally from proximal to distal as well as vertically from base to flooding surface.



QAd8033

Figure 15. Surface in Roxar. Horizons mapped in Seisworks were imported to Roxar for conversion to surfaces, interpolation and smoothing. They were then imported into Geoprobe for visualization.

Observations and Discussion

Within the Mad Dog dataset, the three distinct domains (inboard, escarpment, and outboard areas) have their own unique and dominant structures. The Poseidon mini-basin, Mad Dog Anticline, Mad Dog mini-basin, Sigsbee Salt and Frampton Anticline are the five structural features that influenced deposition in the study area (Figure 16). The minibasins capping the salt sill fit Prather's criteria identifying these features in seismic: high degree of paleotopographic relief, depressions on the modern sea floor, massive salt walls, roughly circular shape, and internal structure that is symmetric to asymmetric (2000). A detailed study of these features can be found in Huang et al. (2009). The basinward limit of the Poseidon minibasin is marked by the still-active salt front and in the landward direction, the Mad Dog minibasin.

The Mad Dog anticline is obscured by the overlying salt. The anticlinal feature formed due to shortening related to the advance of the salt sheet. The Frampton anticline is a larger feature located just basinward of the salt front. A large gas chimney, expressed as bright, chaotic amplitudes that cut vertically across strata, is clearly visible emanating from the strata over the axis of the Frampton structure.

Miocene through Pleistocene strata in the outboard area are interpreted as several sequences of mass transport complexes and large leveed channel complexes. These deposits appear as high amplitude, chaotic to amalgamated seismic facies. It is one of

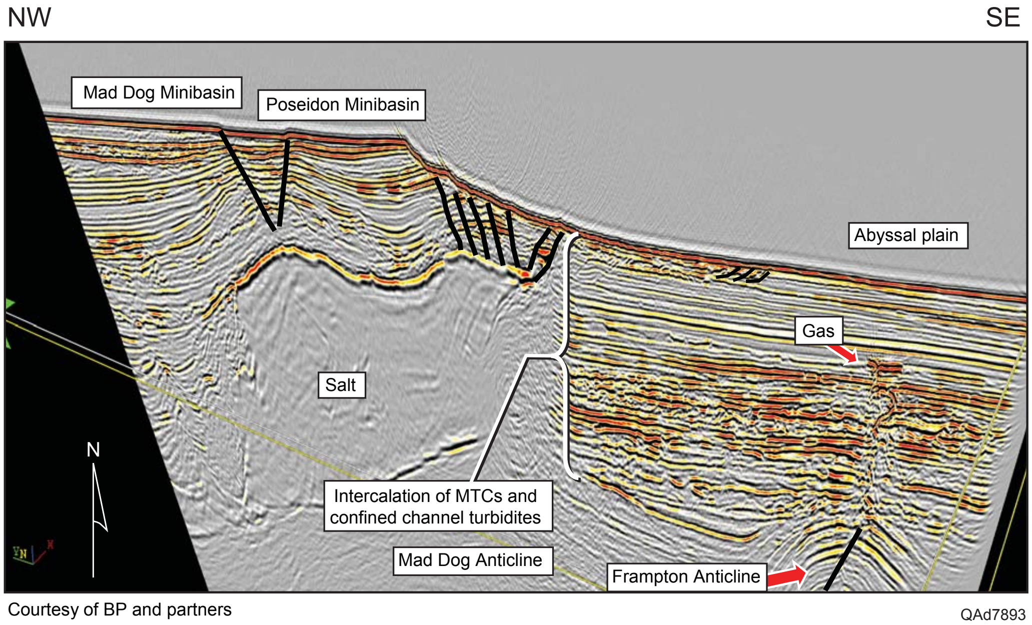


Figure 16. Seismic Line showing major facies and domains. Northwest-Southeast seismic line showing main seismic facies and structural domains within the Mad Dog dataset. The Frampton Anticline is a feature within the Atwater Fold and Thrust Belt which runs parallel to the Sigsbee Escarpment. The Mad Dog anticline lies directly beneath the southern edge of the Sigsbee Salt. Both of these folds formed due to shortening associated with salt advance through gravity sliding. The Poseidon and Mad Dog Minibasins lie just north of the escarpment formed by the still actively mobile Sigsbee Salt.

these large channel complexes that is the focus of this study (Figure 17). This complex system is clearly evident in the inboard and outboard region of the dataset (Figure 18).

Three primary bounding surfaces were mapped across the study area. These surfaces are extensive within the study area and constitute the basal surface bounding the master levee complex (jlm_base_levees), the basal surface bounding the incising confined channel complex (jlm_base_channel_complex) and the master flooding surface over the entire system (jlm_flooding_surface). Table 1 contains detailed descriptions of these surfaces.

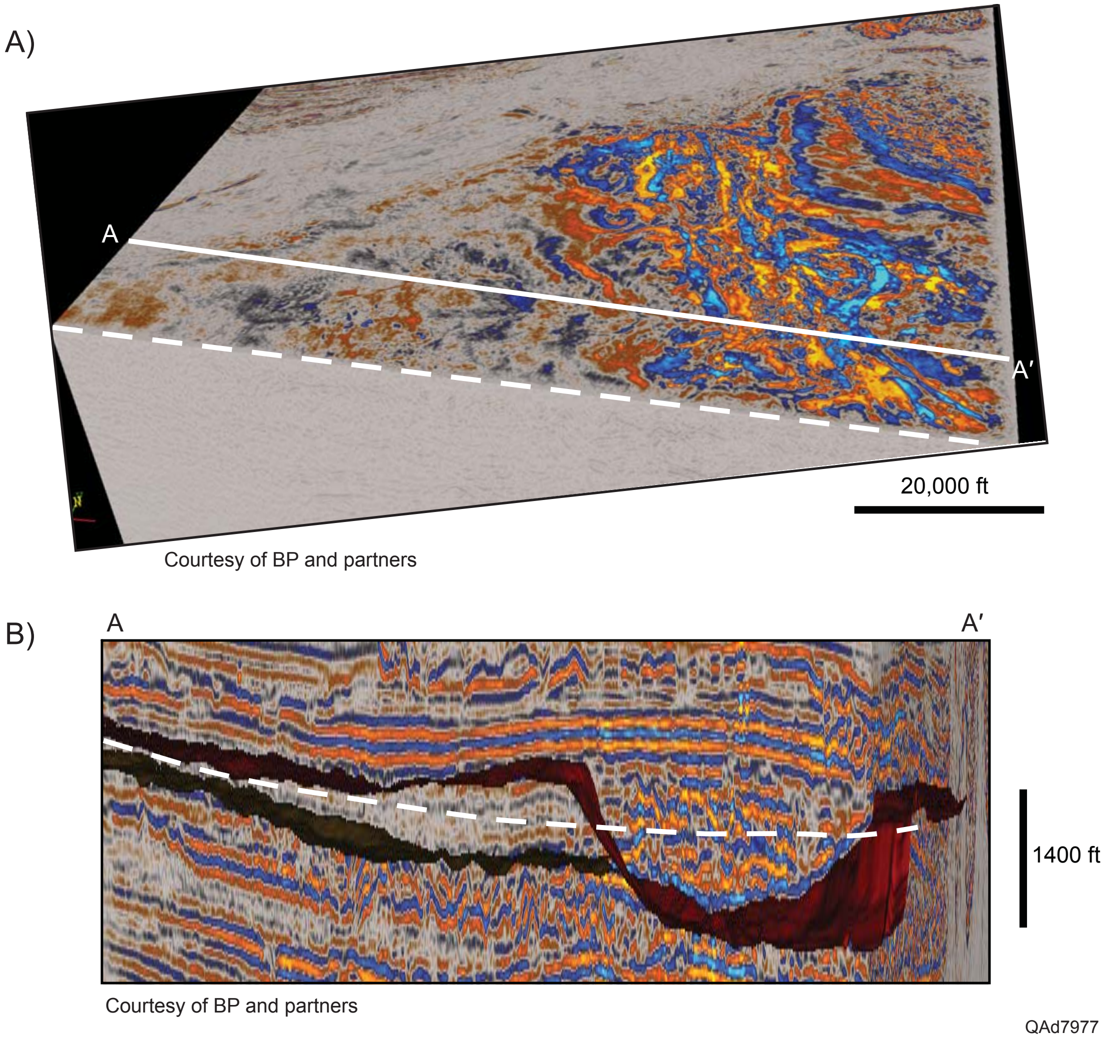


Figure 17. Three-dimensional view of the large channel system. A) Seismic volume showing depth slice illustrating high amplitude meandering channel fill in plan view. Solid white line A-A' is the vertical plane of the seismic line in Figure 17 B. B) Volume showing seismic line view of the channel system, highlighting the differences in channel and levee fill. Dotted line is the horizontal plane of Figure 17 A.

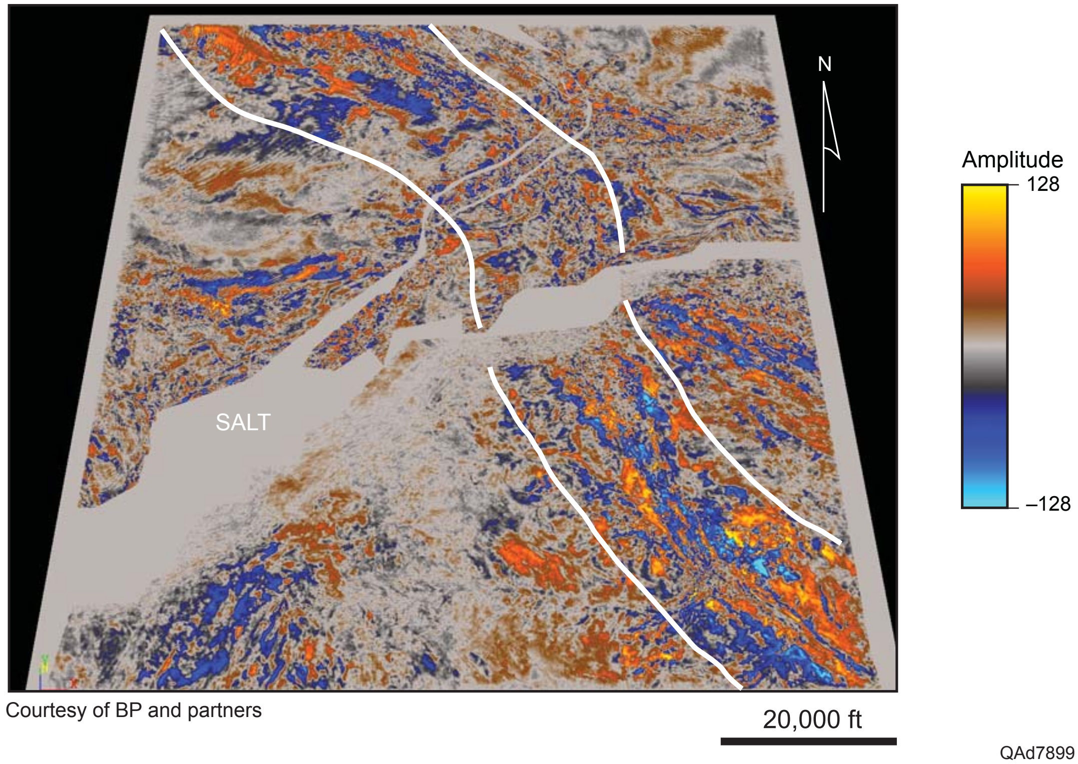


Figure 18. Flattened seismic volume. A) Map view of seismic volume flattened on time-equivalent horizon in the minibasin and outboard area showing continuity of large scale incised valley system. Bright amplitudes illustrate channels sweeping downdip.

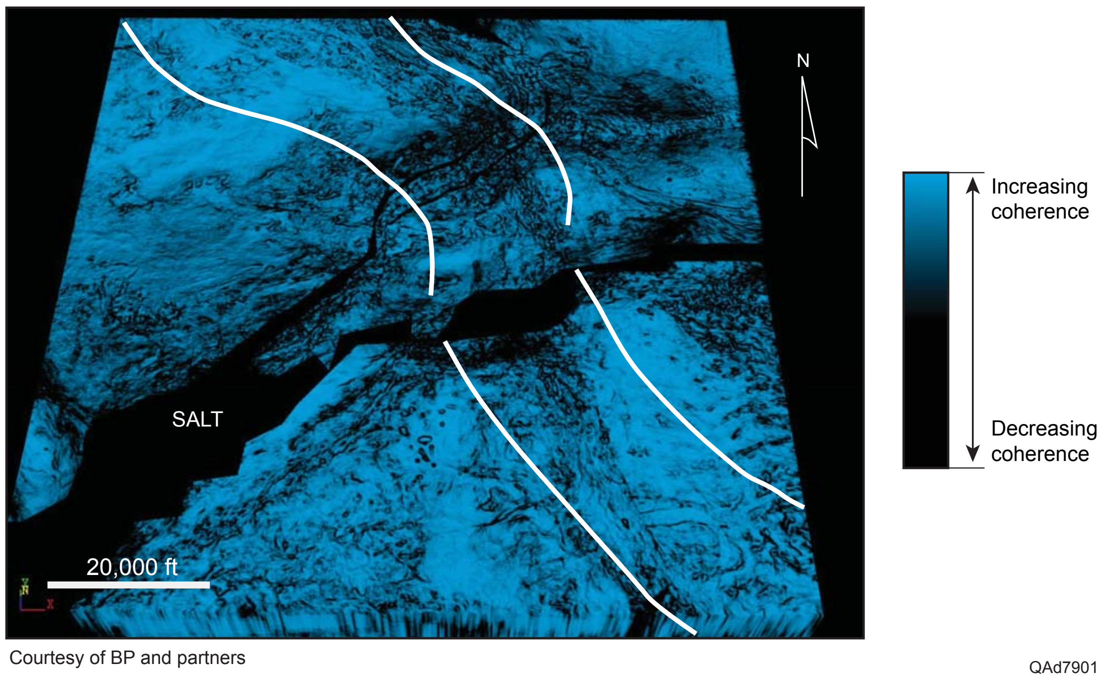
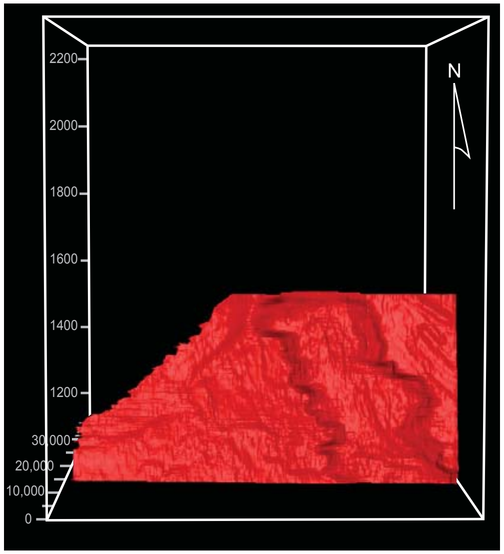
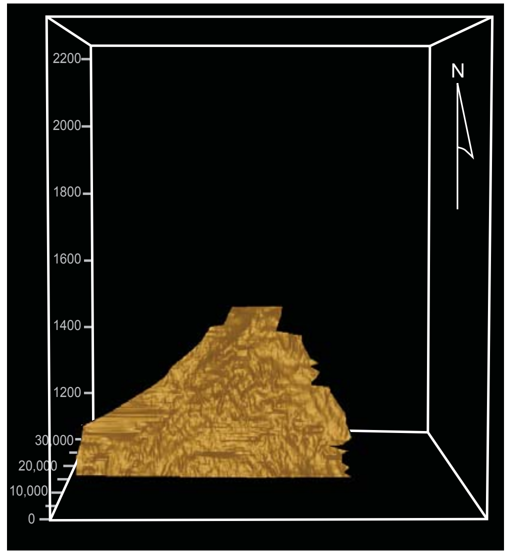


Figure 18 B. Map view of semblance volume flattened on time-equivalent horizon in the minibasin and outboard area showing complex channel fill.



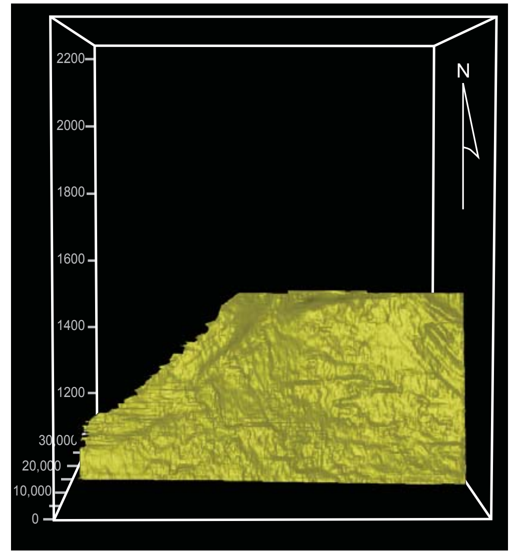
Horizon Name: jlm_base_channel_complex
Surface Classification: Erosional surface

Description:
The base of the channel complex is marked by a high amplitude, continuous to discontinuous (varies along dip) reflector. The channel cuts approximately 400 feet into the previously deposited fan and is overlain by amalgamated channel fill. This basal surface appears composite, i.e., multiple phases of development are evident. There is no apparent basal MTC morphology or material in the lower channel fill. Phases of undercutting and slump widening of the valley are evinced within the channel fill. Margins are irregular in plan view, likely the result of margin failure, as well as meanderbelt translation. A relatively straight, narrow central furrow runs along the axis of the channel complex. This is interpreted as the earliest channel incision that later widened through the above mechanisms. In the proximal area, the axis of the channel is roughly 5480 feet below the seafloor (depth to seafloor is 6760 feet). In the distal reaches of the dataset, the base of the channel is 4920 feet below the seafloor (depth to seafloor is 7400 feet).



Horizon Name: jlm_base_base_levees
Surface Classification: Conformable Bedding Surface

Description:
The base of the levees is a moderate amplitude, continuous reflector. It is conformable with overlying low amplitude levee facies. The surface is underlain by chaotic facies deposited during a previous fan development. Levee heights decrease markedly downdip. Measured just adjacent to the channelform, levees are 760 feet just off the salt and 1120 feet in the distal reaches.



Horizon Name: jlm_flooding surface
Surface Classification: Abandonment Surface

Description:
The surface which caps both the channel complex axis and levees is a high amplitude, continuous reflector. Directly above the channel fill, the horizon is slightly irregular, marked by thinning and local pinching out of the reflector. The surface is conformable with strata above and below, and is capped by high amplitude, continuous reflectors. This surface is relatively smooth. There is no relief of levees above the margins of the channel, and no truncation of reflectors along the top of the levee packages, implying that, at the time of final abandonment, the channel complex fill was the same height as the levees, and the current morphology is a depositional, and not erosional feature.

QAd8037

Table 1. First order surfaces mapped in association with the large confined valley systems of this study.

The large channel-levee complex is approximately 20,000 feet across with levee heights ranging from ~760 feet in the proximal, salt-adjacent area to nearly 1120 feet in the distal portion of the dataset. Well-defined levees extend 19,000 feet away from the axis of the channel. The channel levee complex lies directly above the Frampton. There are two distinct seismic facies present within the system (Figure 19). Channel fill is high amplitude (Figure 20), moderately continuous, interspersed with some valley-confined chaotic facies. Most chaotic facies occur in the lower channel fill, while the upper potion tends to have more continuous reflectors (Figure 21). Levees are low amplitude and contain continuous reflectors that pinch out and thin to the west, away from the channel complex.

The basal container, or valley, appears to be formed through channel migration and failure of the channel margins (Figure 22). Channel complex formation and fill can be divided into five main phases, from initial incision through final abandonment and filling with fine sediment (Figure 23). These phases are:

1. Initial straight channel incision. Low sinuosity. There does not appear to be any significant association of mass transport deposits with this incision.
2. Continued straight incision. Low sinuosity. Appears to be a time period of MAP development in the downdip portions of the valley.

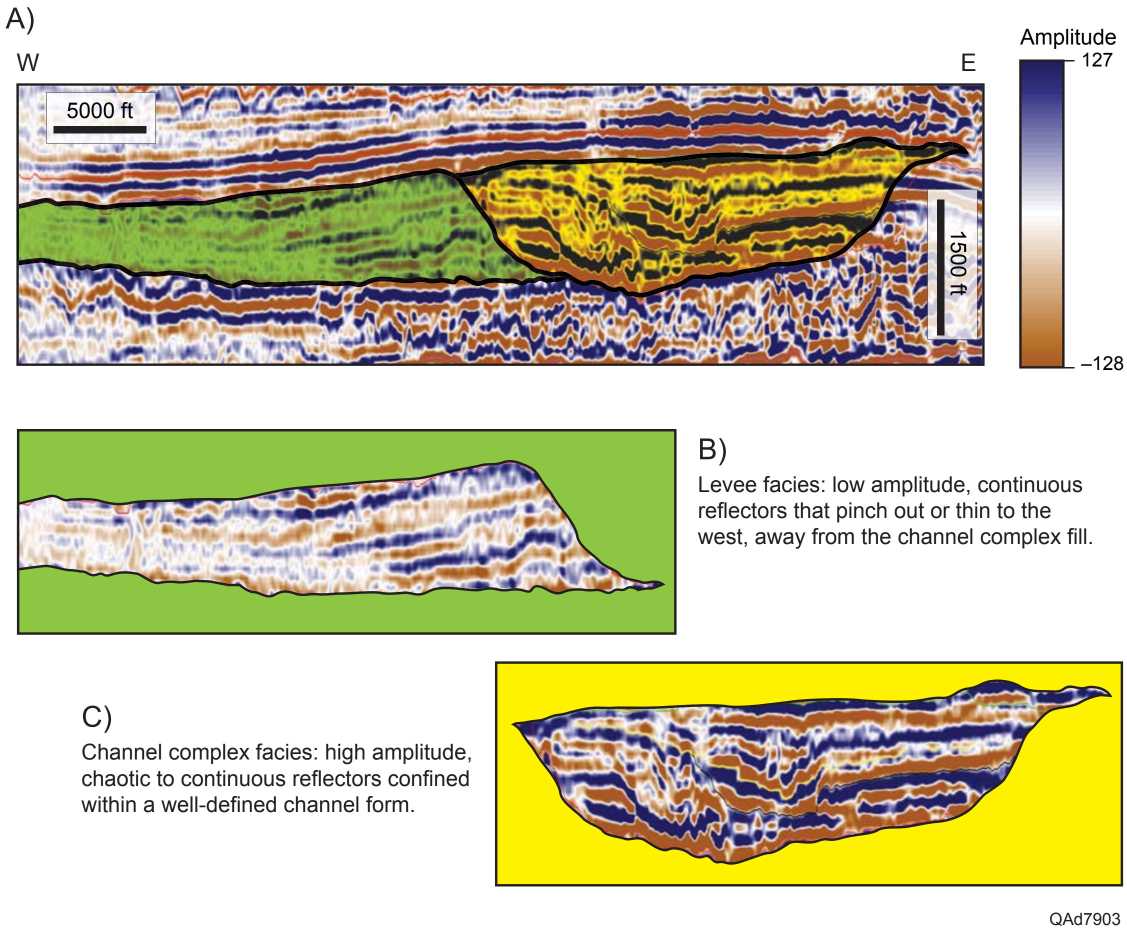


Figure 19. Seismic facies. Two main seismic facies are present within the channel complex: A. Seismic line showing channel levee complex overlying previously deposited mass transport complex B. Levee facies C. Channel Complex Fill Facies.

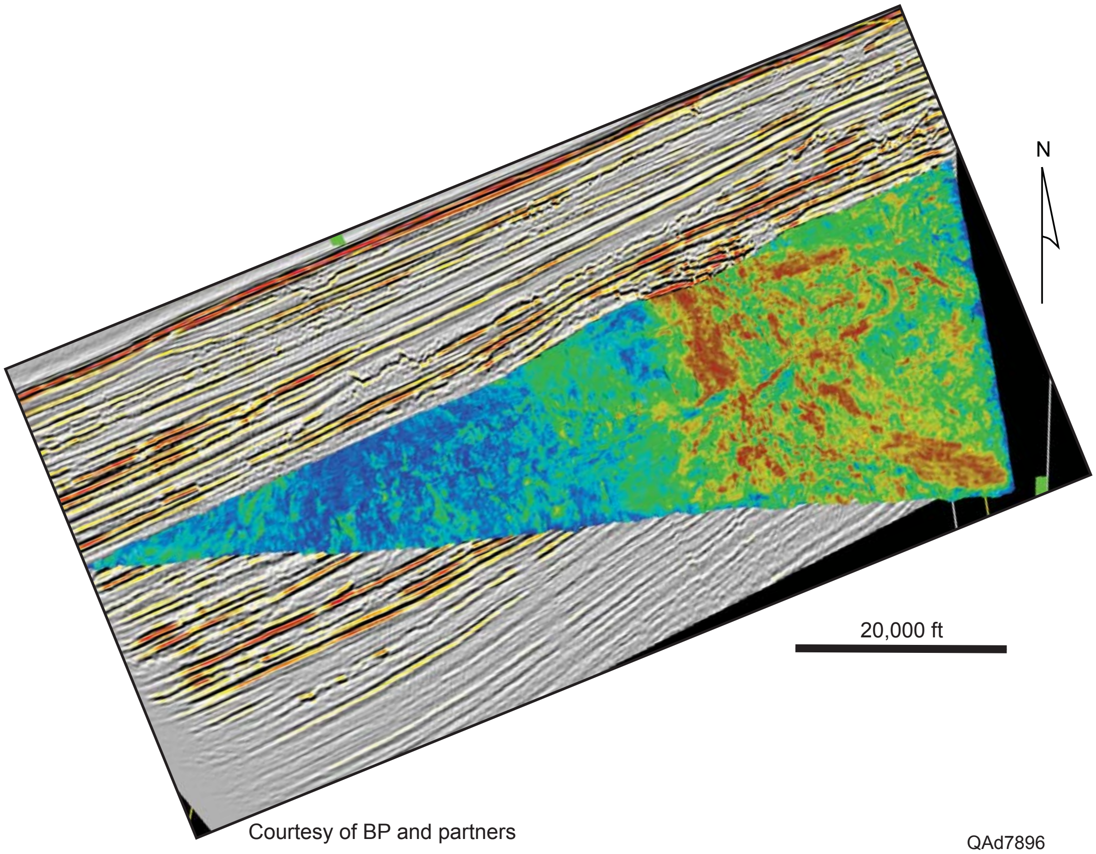


Figure 20. RMS amplitude showing complex channel fill, characterized by high amplitude channel fill and meanderbelt translation. Warm colors indicate high amplitude while cool colors indicate low amplitude. (Huang et al. 2009)

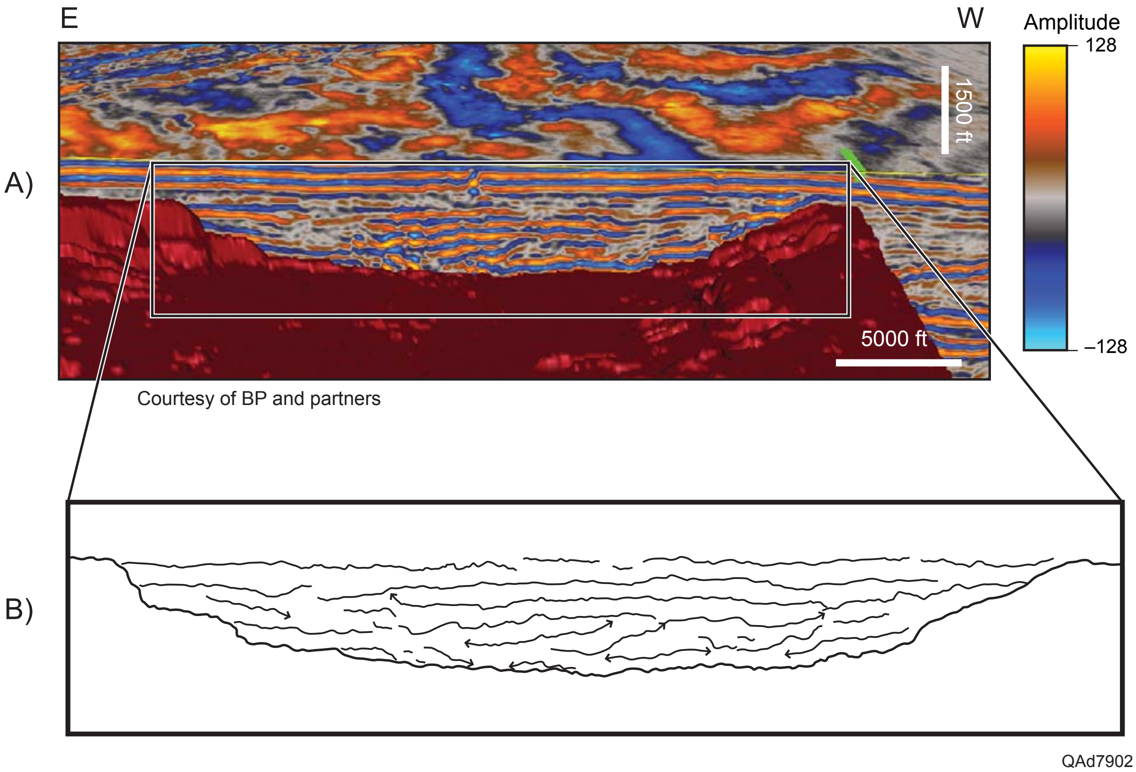


Figure 21. Complex nature of channel fill A) Seismic volume Incised valley complex has two scales of bounding surfaces. Red surface represents the base of valley complex. B. Line drawing illustrating truncation terminations within interior accretion packages. The most chaotic facies are present in the deeper portion of the channel fill.

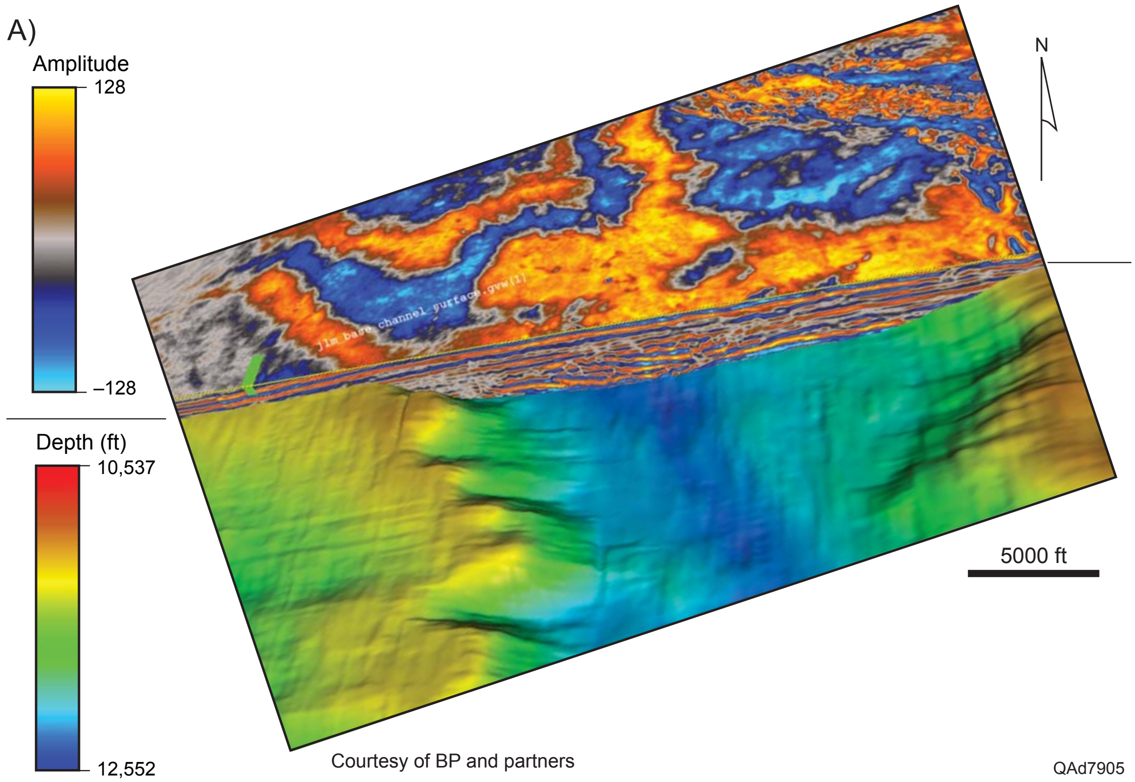


Figure 22. Composite valley surface. The incised valley system widens through two major methods which are discernible in seismic. A) Low amplitude chaotic facies along valley margins represent sidewall slumping along valley margins

B)

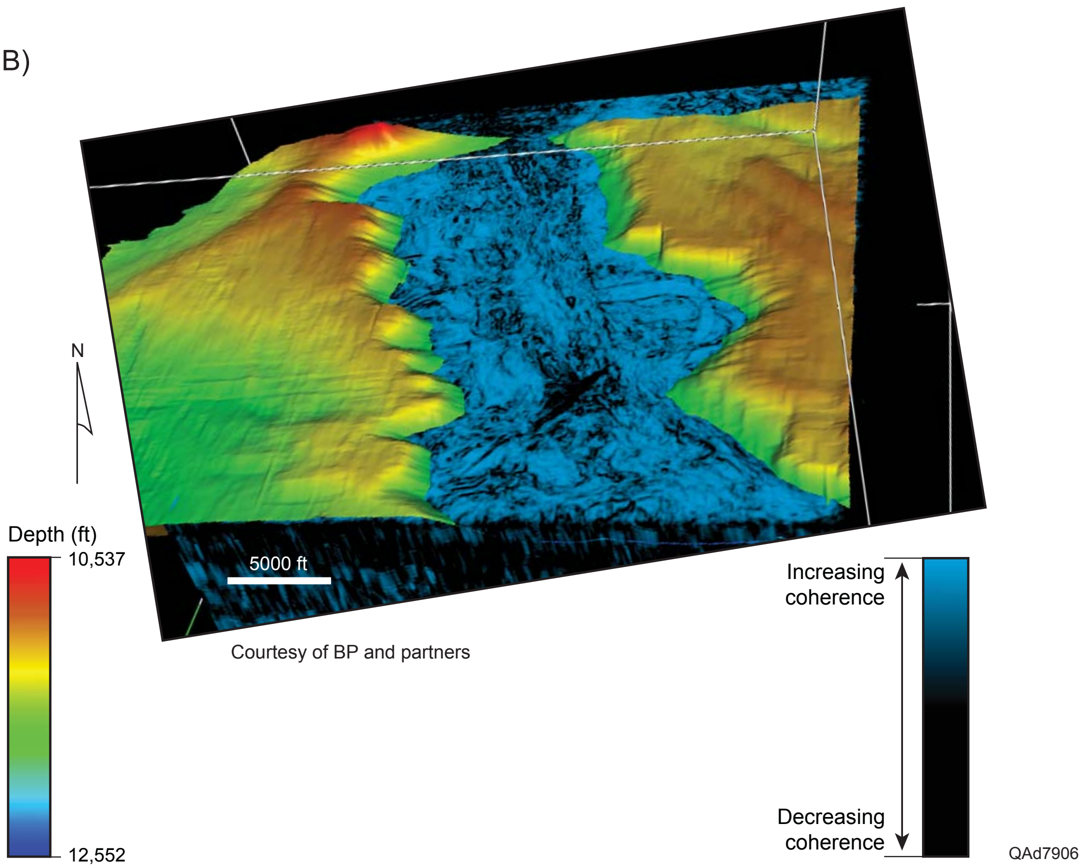


Figure 22. B) The valley widens through channel meanders. Channels appear to take advantage of sidewall slumping to increase their meanderbelt width.

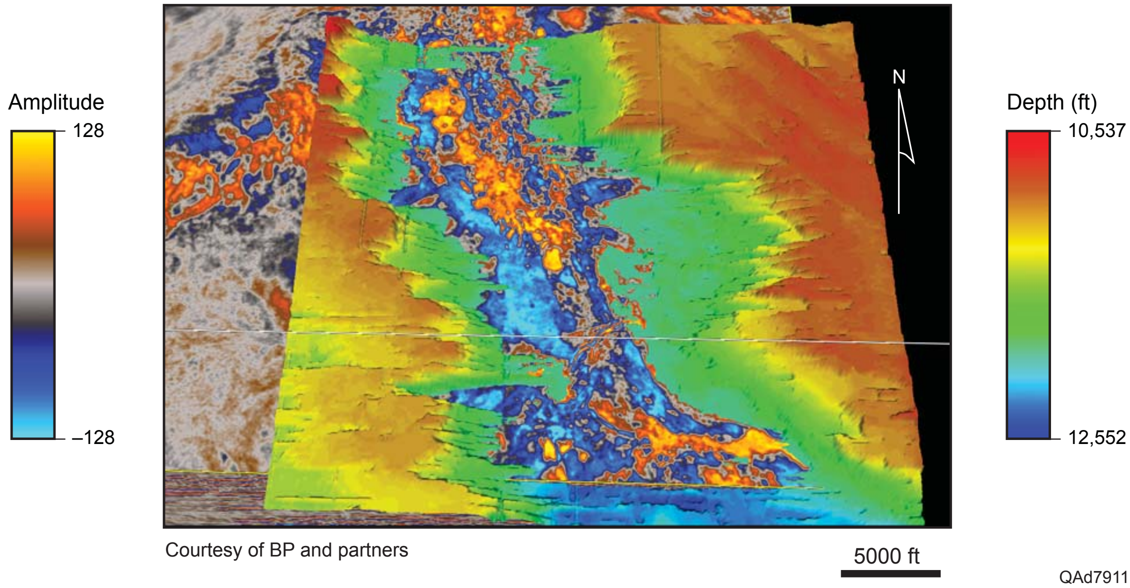


Figure 23. Phases of valley fill. Valley surface intersecting seismic volume. A) Phase 1: Initial straight channel incision. Low sinuosity. There do not appear to be any significant MTC deposits associated with this incision, or at least they are not preserved.

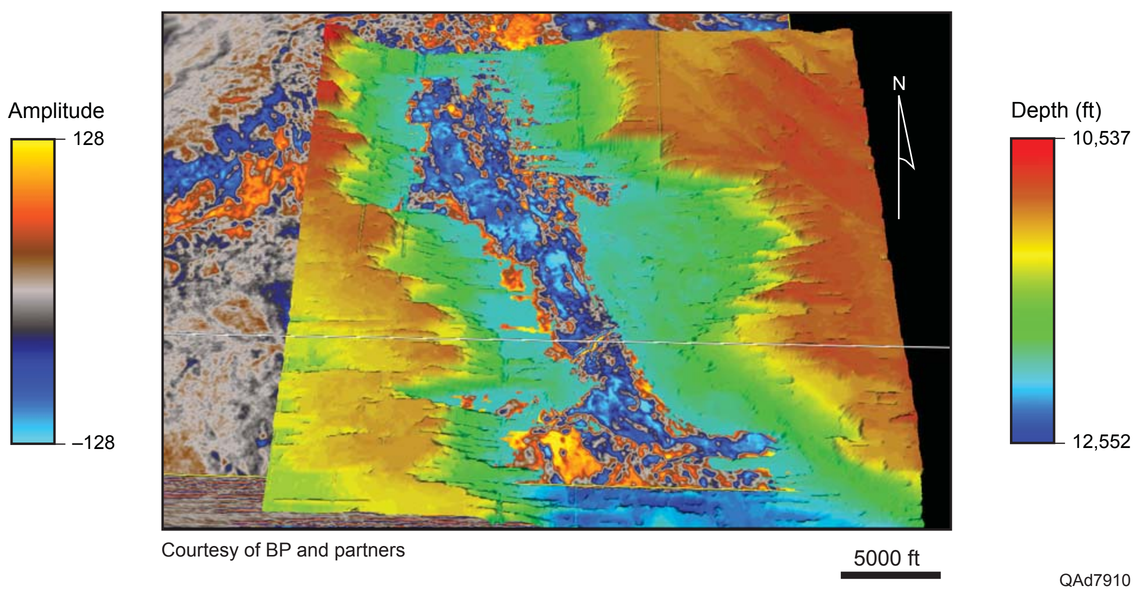


Figure 23. B) Phase 2: Initial straight channel incision continues. Appears to be a time period of MAP development in the downdip direction.

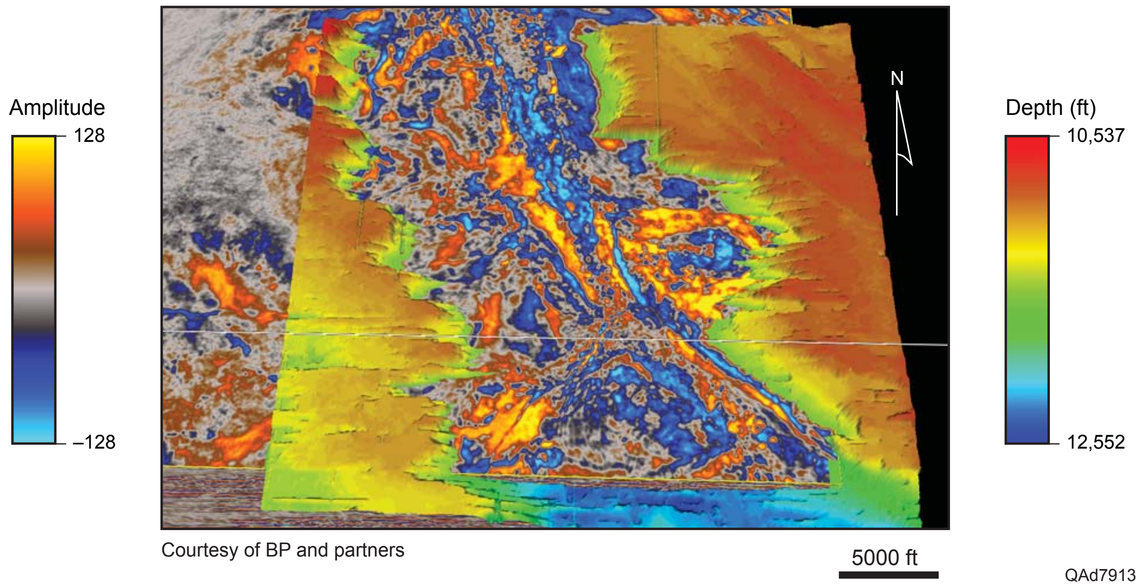


Figure 23. C) Phase 3: Failure of channel margins creating chaotic seismic facies. Valley widens through either lateral channel swing and incision into surrounding master levees, possibly occupying sites of wall failure. High sinuosity Development of internal LAP, MAP surfaces.

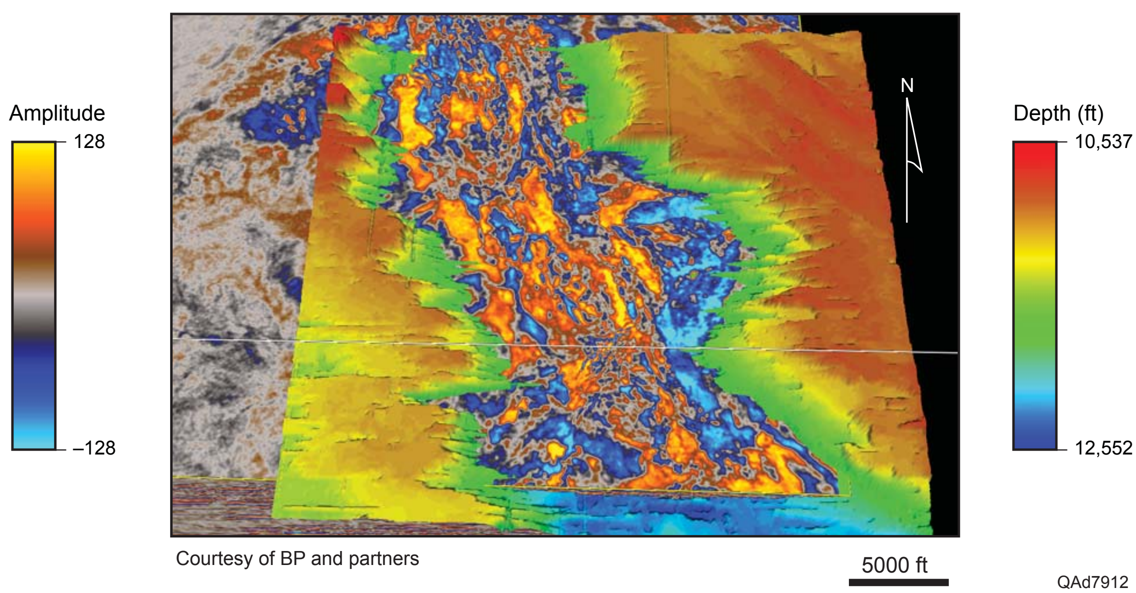


Figure 23. D) Phase 4: Interior channels sweeping down dip. Continued failure of channel walls creating chaotic deposits on channel margins.

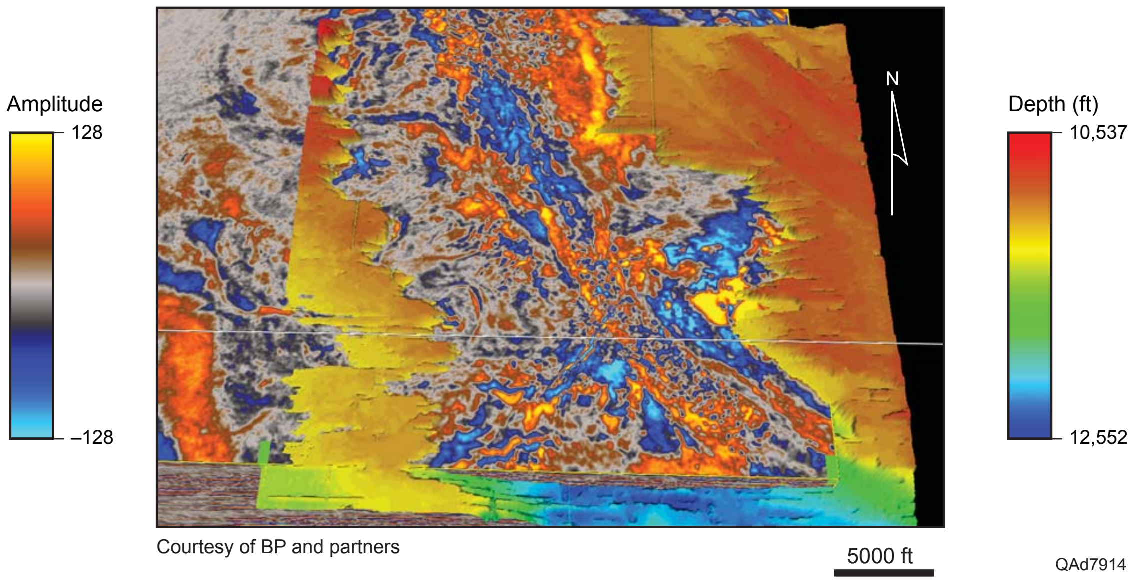
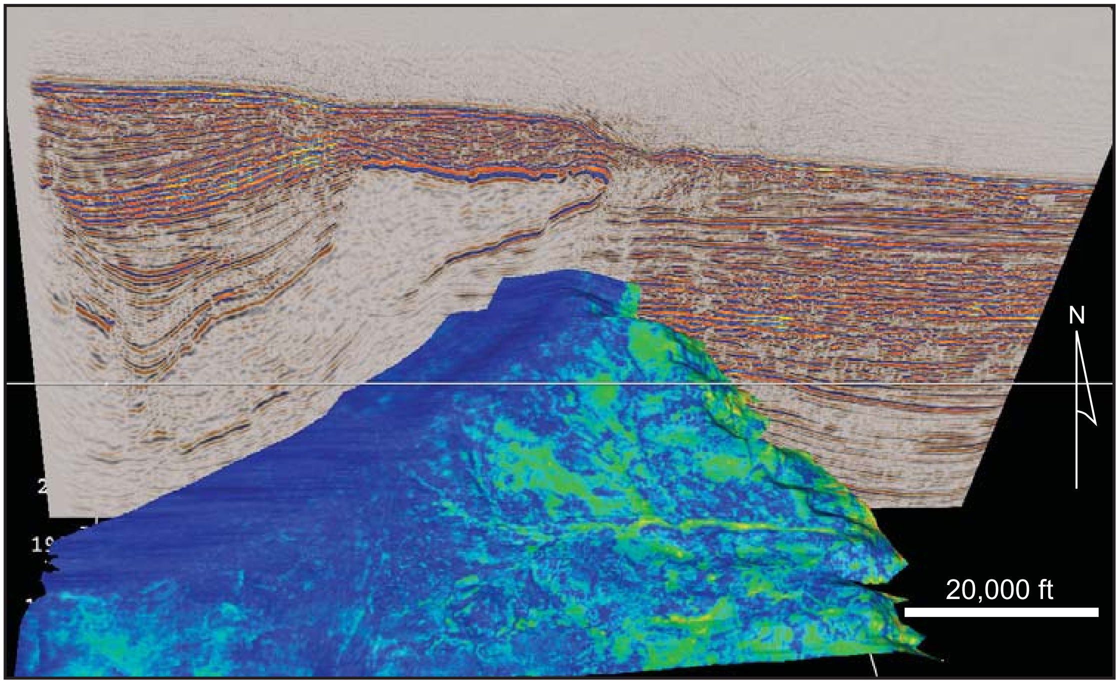


Figure 23. E) Phase 5: Second phase of channel straightening Massive fill of remaining valley space. Continued failure of channel margins. The axis of the channel complex is dominated by a later phase of straight channel incision sweeping downdip.

3. Failure of channel margins and timing of deposition of chaotic seismic facies. Valley widens through lateral channel swing and incision into surrounding master levees, possibly occupying sites of wall failure. High sinuosity development of internal LAP and MAP surfaces
4. Interior channels sweeping down dip. Continued failure of channel walls creating chaotic deposits on channel margins
5. Second phase of channel straightening and massive fill of remaining valley space. Continued failure of channel margins. During this late stage, a dendritic drainage forms off the west of the valley on top of the levees (Figure 24).

Individual channel systems within the valley show some distinctive morphologies. Meanderbelt translation is observable in plan view, but it is not traditional translation in the downstream direction. The channel appears to be migrating up-stream in the system (Figure 25). There are several possible explanations for this atypical migration, including uplift associated with the more distally located Frampton anticline, thrusting of salt and subsidence in the proximal areas of the valley, or as some localized channel readjustment processes caused by simple tectonics associated with the Atwater fold belt.

Contained between the basal confined channel complex surface and the overlying master flooding surface, ten surfaces were mapped internal to the channel fill and are confined wholly within the channel fill (jlm_lap1 thru jlm_lap10). These surfaces are detailed in Table 2.



Courtesy of BP and partners

QAd7915

Figure 24. Stratal slice. RMS Amplitude extraction overlay on stratal slice between the base and top of levees. Hot colors show a dendritic drainage pattern in the upper reaches of the levee. This is the only large scale sedimentary feature visible on the levees.

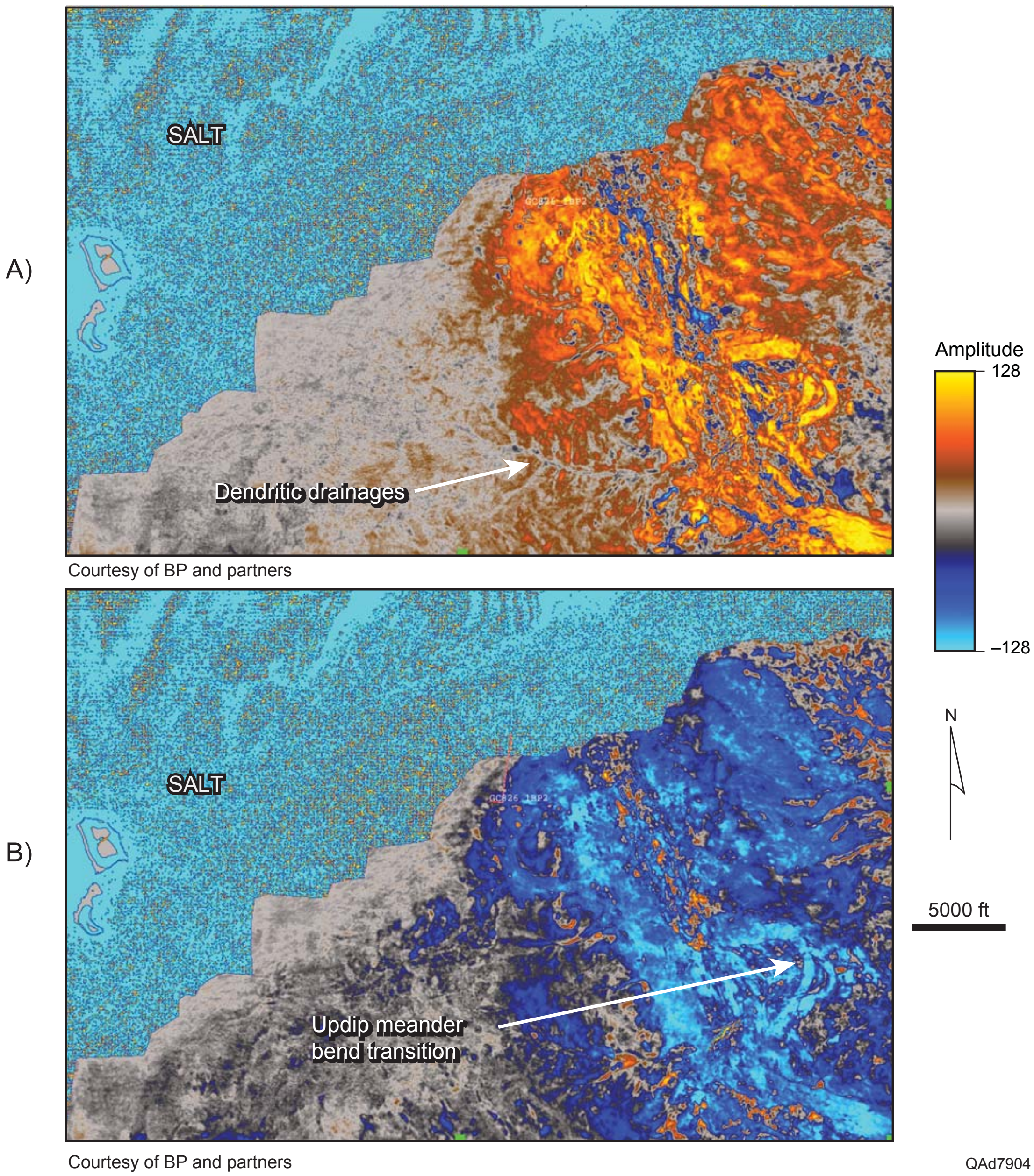


Figure 25. Depth slices illustrating complexity of channel complex evolution. A) A dendritic drainage pattern is visible to the west of the confined channel complex. B) Meander bends appear to be translating updip instead of traditional downdip migration, possibly related to the growth of the Frampton anticline to the south.

Table 2. Ten surfaces mapped within the internal fill of the studied Poseidon Valley.

A) Surfaces 1 and 2.

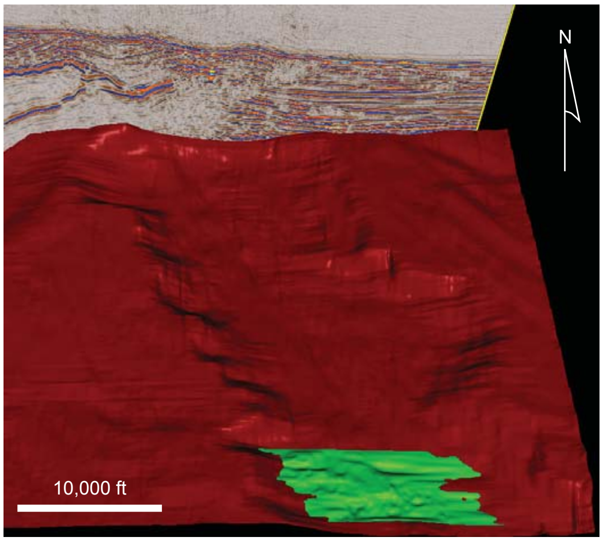
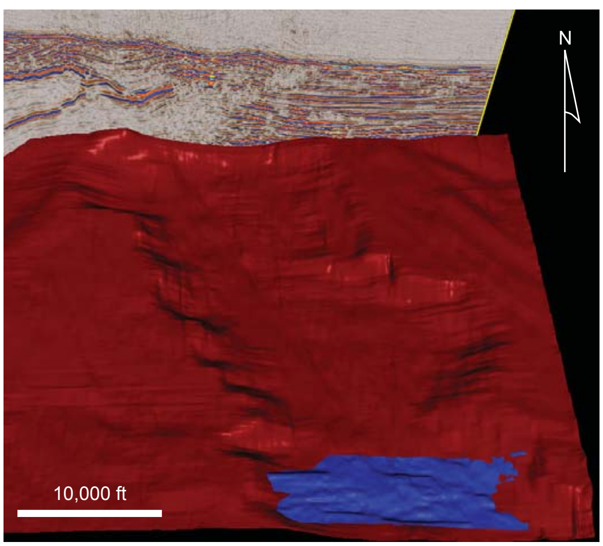
Surface	Surface Classification	Description
	Mid-channel Accretion Package	Surface 1 is a low-angle horizon which terminates against the base of the channel to the east and north. Slope is approximately .02.
	Mid-channel Accretion Package	Surface 2 parallels and directly overlies surface 1. Slope is approximately .02

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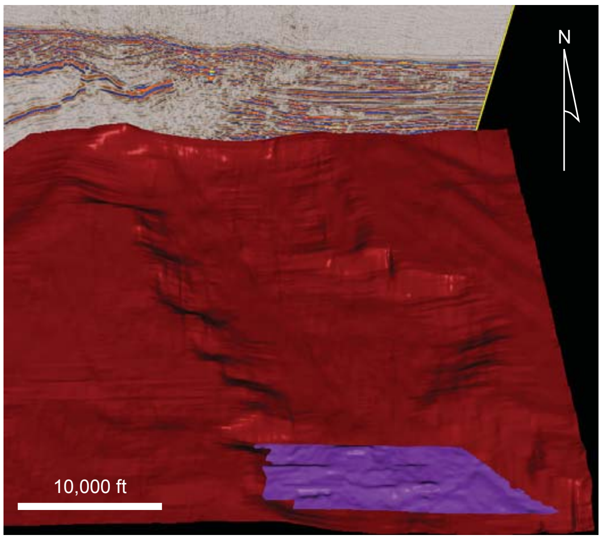
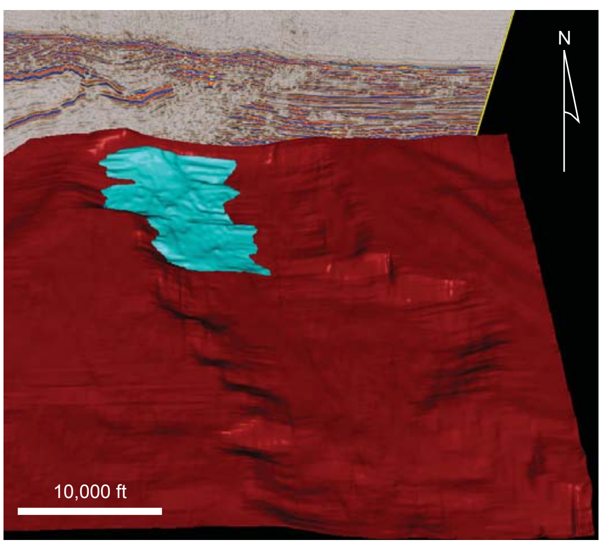
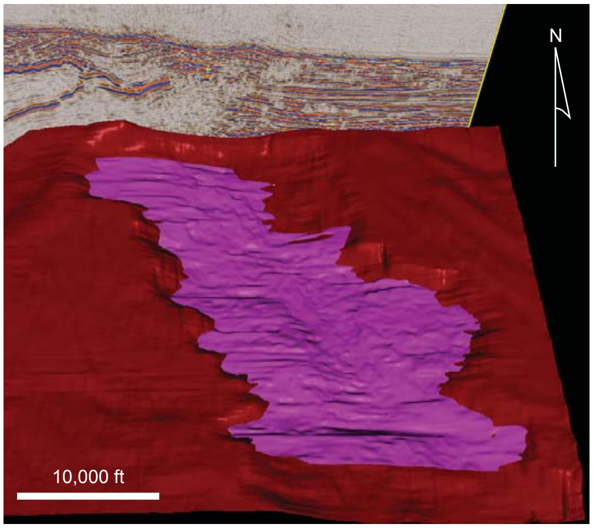
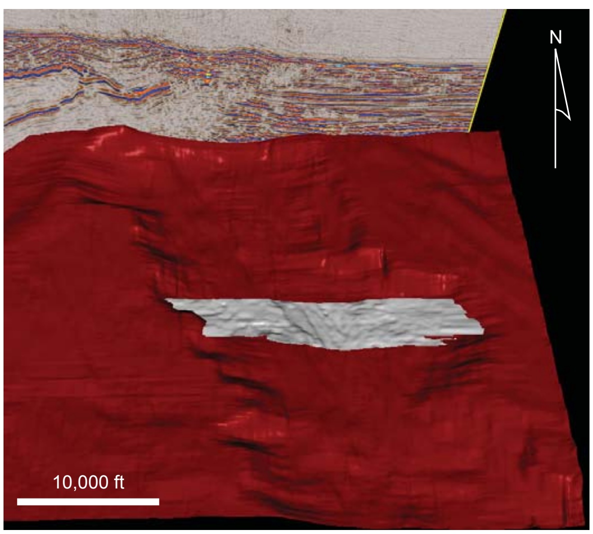
Table 2, cont. B) Surfaces 3 and 4.

Surface	Surface Classification	Description
	Mid-channel Accretion Package	Surface 3 has roughly the same areal extent and surfaces 1 and 2. Slope is approximately .02.
	Lateral Accretion Package	Surface 4 represents the earliest infilling of the proximal portion of the channel. Slope varies across the surface, but is significantly steeper than the more distal surfaces.

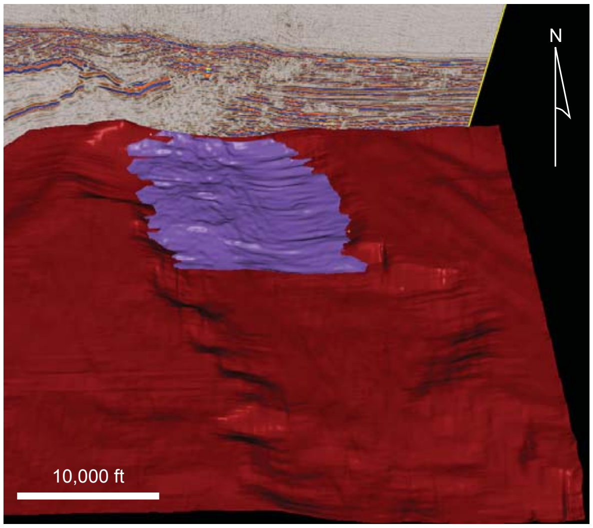
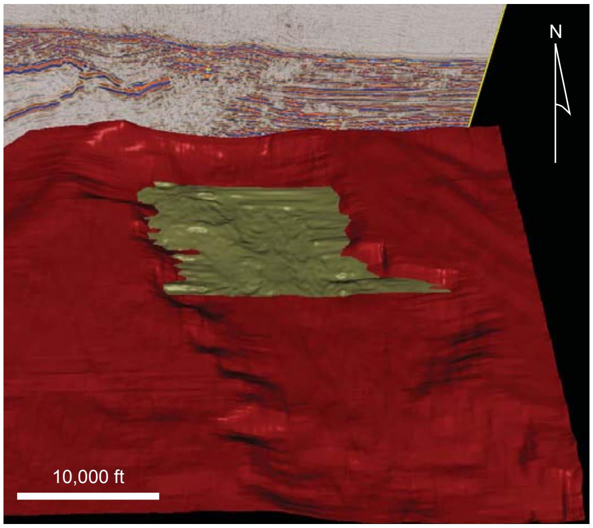
QAd8036(a)

Table 2, cont. C) Surfaces 5 and 6.

Surface	Surface Classification	Description
	Flooding Surface	Surface 5 represents a period of extensive valley widening and subsequent infilling, indicating an abandonment surface. A continuous channelform depression through this horizon indicates that reactivation occurred some time after abandonment.
	Meandering Channelform	Surface 6 is an areally restricted horizon located in the more chaotic middle reach of the channel. It lies directly above Surface 5 and parallels the channelform therein. Surface 6 represents the continuation of the second phase of meandering fill.

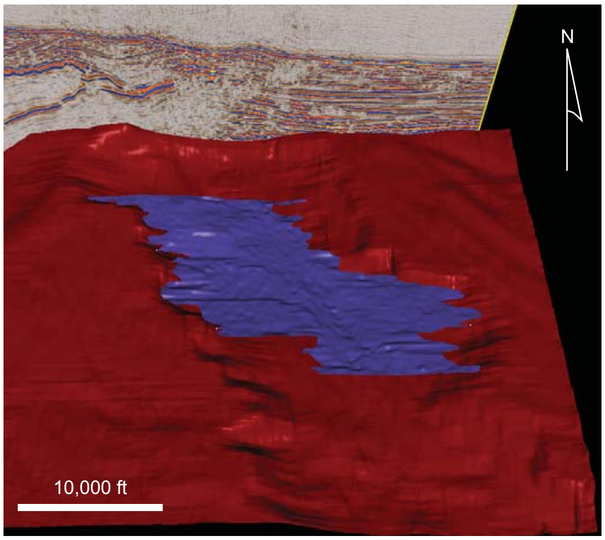
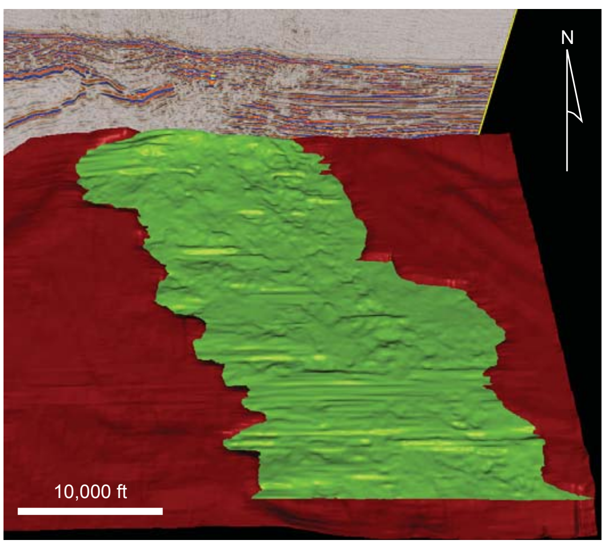
QAd8036(b)

Table 2, cont. D) Surfaces 7 and 8.

Surface	Surface Classification	Description
	Lateral Accretion Package	Surface 7 is an areally-extensive horizon located in the proximal portion of the channel complex. It is an asymmetric surface with a channel to the east and flattening out to the west. This surface marks the initiation of the second phase of proximal lateral fill packages.
	Lateral Accretion Package	Surface 8 lies nested within the channelform depression in Surface 7. It represents the infilling of the channel and continues Lateral Accretion Package development.

QAd8036(c)

Table 2, cont. D) Surfaces 9 and 10.

Surface	Surface Classification	Description
	Initiation of Flooding	Surface 9 is an extensive low angle horizon with a slope of approximately .01. The channel first identifiable in Surface 7 is becoming less pronounced, indicating a final phase of infilling.
	Continuation of Flooding	This horizon parallels the final capping abandonment surface. The late phase of the valley-wide infill is characterized by lower-amplitude parallel to subparallel reflectors.

QAd8036(d)

Interior surfaces mapped within the channel vary in terms of their morphology, slope and location in the system. Both types of accretionary forms, LAPs and MAPs, are present in the large-scale channel-levee system in the Mad Dog area and their distribution depends upon proximity to the fan and gradient of the system. In the more proximal area, close to the escarpment, slopes of interior surfaces are roughly 0.08. In the more distal portion of the channel, these surfaces flatten out considerably to only about 0.02 (Figure 26). Proximal surfaces are interpreted at LAPs because of the steeper slopes as well as the fact that their direction of build is toward the channel axis. The distal packages with the lower slopes fit more closely with the MAP description. These surfaces show up-valley accretion, aggrading toward the salt front instead of advancing toward the channel axis. Development of these backstepped deposits coincides with a slight steepening of the channel gradient just north of these packages. This is consistent with Pickering's description of the occurrence of these packages in the Tabernas Basin (2001).

LAPs represent the various lateral positions of the channel through time. They preserve the position of the depositional bank (Abreau et al. 2003). LAPs accrete laterally within the channel and to a lesser degree, downdip. There is some debate about whether this accretion occurs in a manner similar to point bar aggradation in fluvial systems (Abreau et al., 2003) or as tractional deposits on the outer banks of turbidity flows and grow toward the axis of the system. In this setting, the latter appears to be the case.

One well penetrates the western axis of the valley fill (well GC826 1BP2). Well Log gamma ray signatures show several fining-upward cycles on a slightly smaller scale than the inter-lap thicknesses (Figure 27). Thick shales occurring in the log in association with these surfaces may represent clay drapes similar to those documented in studies of the Capistrano Formation, western California (Stewart et al., 2008)

A)

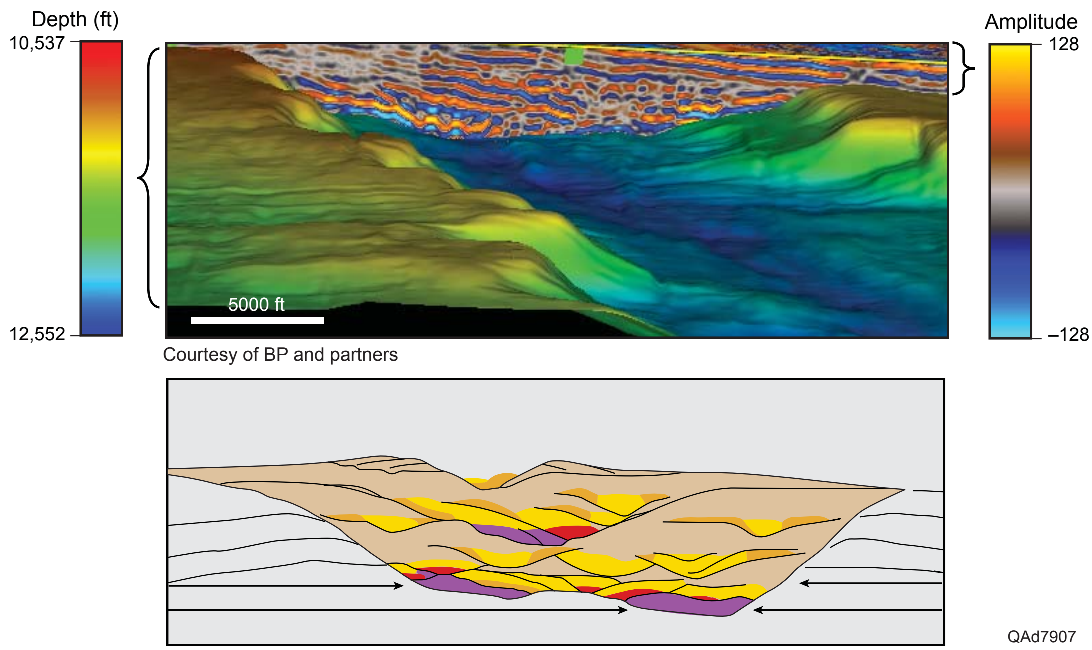


Figure 26. Channel morphology varies along dip. Moprphology of elements within the system vary with proximity to the salt front. A) In the more proximal area, the slopes of accretion packages are approximately 0.08. Channel complex fill is more amalgamated and reflectors tend to be less continuous. This portion of the channel complex closely resembles the mid-slope in the depositional model.

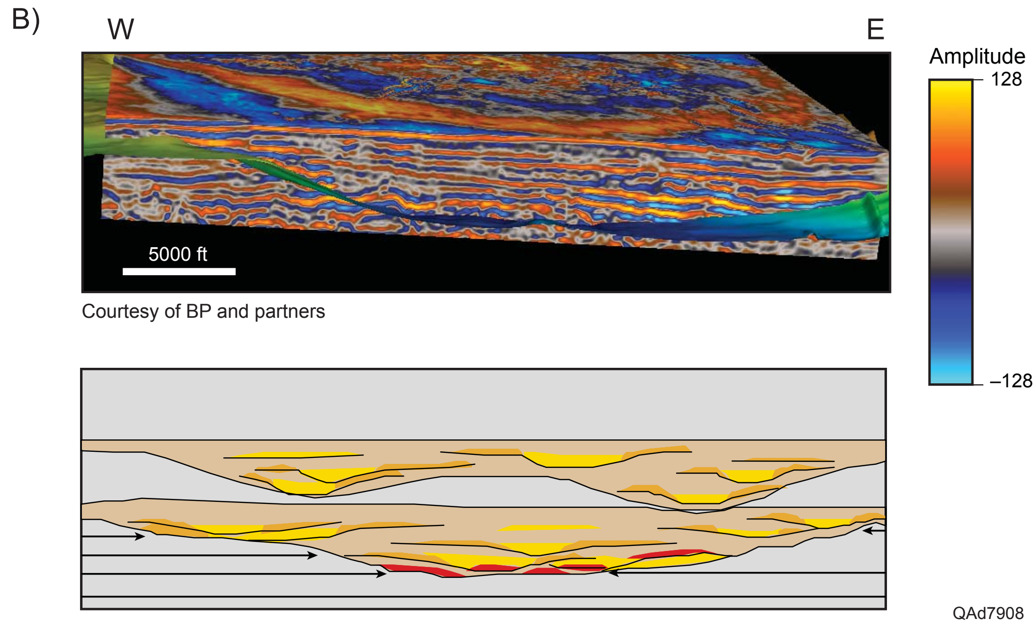


Figure 26. B) In the more distal area closer to the southern edge of the dataset, accretionary packages have a slope closer to 0.02. Reflectors are more continuous across the width of the channel complex. This portion of the channel complex is roughly equivalent to the lower slope in the depositional model.

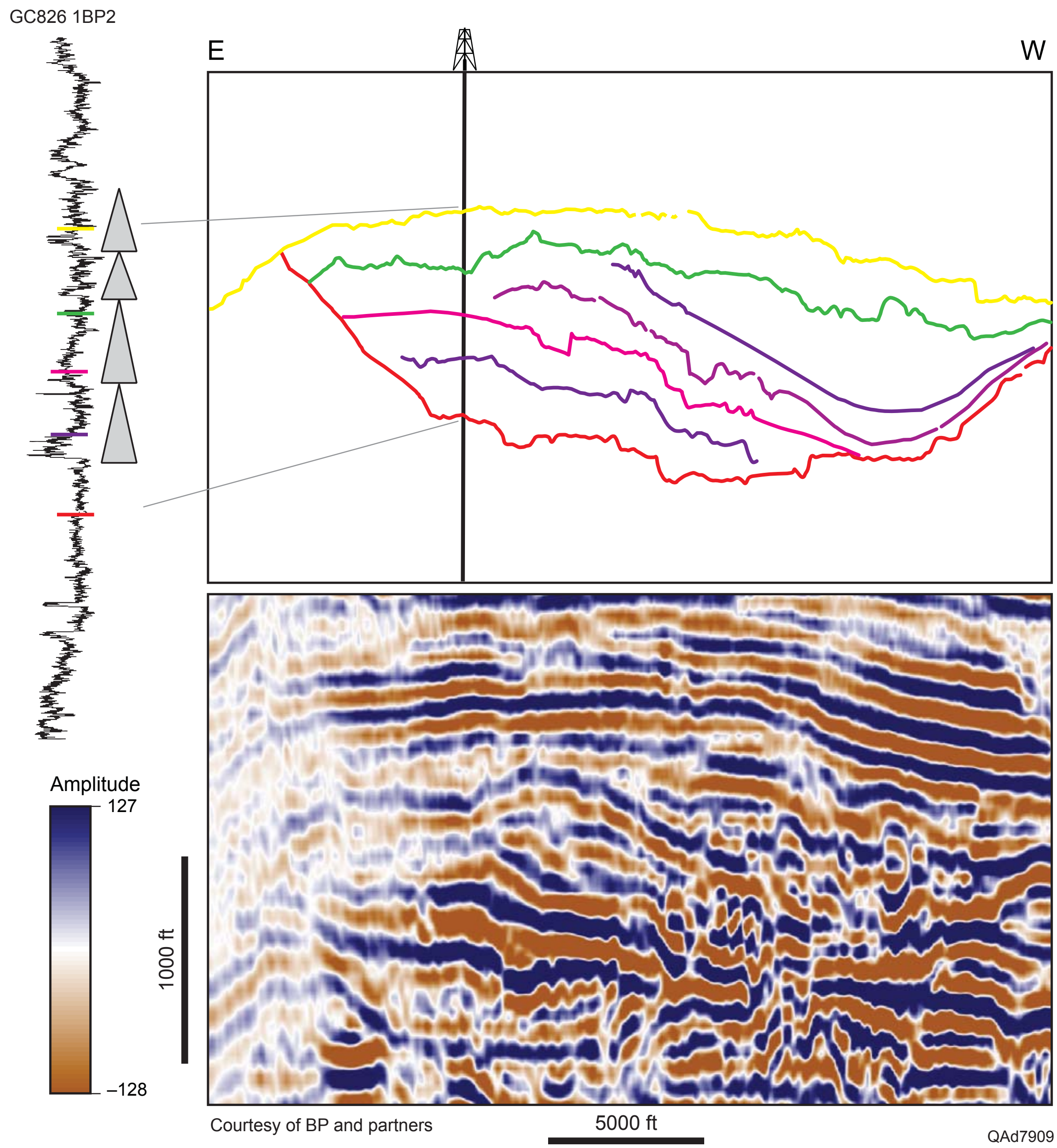


Figure 27. Clay drape signature in well log. Well GC826 1BP2 penetrates the margin of the channel complex near the salt front. The ratty well log signature results from the presence of 1-3 meter thick mudstone/siltstone drapes deposited between flow events. The well log shows four fining-upward cycles on a slightly smaller scale than the inter-lap thicknesses that occur within the channel complex representing periods of high activity and relative quiescence in the system. The depth of the yellow horizon within the well is 12,240 feet below sea level. The red horizon is 13,350 feet below seal level.

Comparison of the Mad Dog Confined Channel Complex with similar systems worldwide

The 3D seismic reflection tool has allowed geomorphologists to study deep-water systems in a way never before possible. Continuous, large-scale images of these deposits have lead to an increased understanding of sequence stratigraphy and how these elements fit into a framework of sea-level cycles. In this way, the scale of seismic studies has been an invaluable asset to the increased understanding of deep-water geology. However, seismic resolution does create limitations in our ability to resolve the details observed in outcrop and the complexity of nature limits our ability to deterministically insert details derived from outcrop and core studies into frameworks mapped in seismic. The small-scale aspects of the system, which often control reservoir heterogeneities, are lost in the big picture.

Outcrop studies have their own drawbacks. The geologist is limited by two dimensional, often oblique views, and there are very few outcrops in the world that expose the full width and breadth of deposits from a single deep-water system. Defining elements seen in seismic can be lost in limited rock exposure (Roberts and Compani 1996). Bridging the gap between seismic and outcrop studies is a key component in understanding deep-water deposition and increasing productivity in these types of reservoirs. A quantitative, as well as qualitative, comparison of the channel-levee complex in this study with other seismic, outcrop and numerical modeling studies will help to bridge these scales. Numerous systems documented in both outcrop and in seismic studies were examined and their character compared and contrasted with the Poseidon Valley to gain insight into character that might exist in the Poseidon system below the resolution of the seismic data, as well as offer an opportunity to place smaller scale outcrop observations within a larger framework. Several of these comparisons are documented below.

GULF OF GUINEA

The study of Tertiary turbidite systems in the Gulf of Guinea in Navarre et al. (2002) focused on the development of a channel stacking hierarchy. The proposed reservoir model contains six stratigraphic units, but only channel complexes, which are bounded by fourth order surfaces and channel stories, bounded by fifth order surfaces, are discernable in seismic. The channel complex studied is roughly 360 feet thick and contains three fining-upward cycles capped by 30-foot thick shaly intervals. Each one of these cycles is interpreted as a channel story. Two types of levees were defined in the system: internal levees within the channel axis and proximal to distal levees on either side of the axis. Five phases of channel evolution were defined based on this system:

- Erosion of the base container and basal infilling, consisting mainly of debris flows or slumps
- Filling of the container with sand bars
- Plugging of the upper reaches of the system with shaly facies, associated with abandonment

- Spilling of deposits laterally to the axis
- Constructive phase creating a positive feature within and on either side of the axis.

The first three stages of channel complex evolution roughly parallel the evolution of the Mad Dog channel complex, except that there is no evidence of slumping or debris flow preserved in the base of the Mad Dog example. While the Gulf of Guinea example is roughly one third of the size of the Mad Dog system, the overall morphology and architectural elements are markedly similar. This similarity of two different sizes of systems implies that, at least within an order of magnitude, element distribution and morphology are not dependent on the scale of the system.

AMAZON DEEP SEA FAN

The Flood and Damuth (1987) study of channel systems in the Amazon Deep-Sea fan discusses the downdip changes in fan morphology. Three distinct domains are described:

- An Upper Fan composed of a large canyon which feeds the slope and contains one large channel perched on a single set of levees (8000 ft wide and 650 ft deep, levees 50 km (31 miles) wide and 3200 ft thick)
- A Middle Fan composed of smaller channels perched on levee systems (levees thin progressively downdip)
- Lower Fan composed of numerous unconfined channels with no levees

The Mad Dog channel complex most closely resembles the Upper Fan of the Amazon in its morphology. A major morphologic character shared by this system and that in the Mad Dog system is the "perched" nature of the channel-levee complex. These channels do not deeply incise the seafloor, but instead sit atop it, surrounded by high levees (in the case of the Amazon fan, approximately 1 km thick). The scale of the Amazon example is similar to the New Guinea example, described in the previous paragraph.

DAHLIA AND GIRASSOL, OFFSHORE ANGOLA

Abreau et al. (2003) studied a channel complex within the Dahlia and Girassol fields, offshore Angola, to define some of the internal architectures of these systems. The base of this system formed due to "migration and avulsion of a single channel ", roughly 2 km (6600 ft) wide and 150 m (about 500 ft) deep whose dimensions remained roughly constant throughout the evolution of the complex. Lateral Accretion Packages are roughly 25-40 m thick in this system. Well logs in the Girassol fields along the outer portion of a LAP show fining upward pattern, indicating that lower portions of the LAPs have better reservoir potential.

The Lateral Accretion Packages in the Mad Dog system compared to the West Africa systems show similarities as well as differences. In the offshore Angola systems, LAPs show a steeply shingled morphology while in the Mad Dog study area, LAPs have a more stacked appearance. The channel-levee complex in the Mad Dog area was not created by the avulsion and meandering of a single channel system, which may account for this difference in LAP stacking patterns. The fining-upward log signature of the LAP packages can be found in both the Angola and Mad Dog area well logs.

Solitary Channel, Spain

The Abreau et al paper (2002) also included forward seismic modeling of Solitary Channel in Tabernas, Spain. The slope channel system at the Tabernas location is approximately 40 m (130 feet) thick and can be traced along 7 km (about 4.3 miles) of outcrop. Seismic modeling was undertaken to determine what architectures would be lost at typical subsurface seismic resolution. This study concluded that deep-water depositional packages like the ones found in the Tabernas outcrop, on the scale of 10 m, would only be able to be picked up on high frequency (65hz) seismic data. This study and problem perfectly exemplifies the knowledge gap that exists between the seismic resolution scale and outcrop scales.

BRUSHY CANYON, WEST TEXAS

Spatial continuity in outcrops is finite and two dimensional, and inferences must be made between outcrops to create a three dimensional depositional frameworks. Gardner and Borer (2000) studied the features of a deep-water turbidite system from the scale of the architectural element (23 ft x 650ft) through the depositional sequence termed "submarine fan conduit complex" (100 ft x 8000 ft wide) along a series of outcrops that expose depositional environments from the upper slope through the basin floor. The extensive nature of the outcrop, allowed them to study the complete hierarchy of fill down to deposits less than a meter thick as well as the source-to-sink spatial distribution. Heterogeneities can be mapped to a very small scale and a regional view of the system is available. This study is an example of one that comes very close to bridging the seismic and outcrop scales.

On the upper slope of the Brushy Canyon study, a large confined channel levee complex can be found. Gardner and Borer (2000) interpret a significant hiatus between incision of the master containment surface and infilling of the valley. This hiatus indicates that the channelform was a non-depositional conduit for a long period after its initial incision. The authors' evidence for such a hiatus includes the presence of "erosional discordances" interpreted to be coalesced slump scars. There is no evidence in the Mad Dog channel system for or against such a hiatus. Therefore, it is interpreted that, in the Mad Dog confined channel, the lateral and medial accretion, likely occurred at various locations within the channel as bypass was active in other localities. There is no reason to believe that this was a vacuous space for some period of time, as we know that does not happen in subaerial river deposits. Rather the fill is a dynamic and ongoing process of deposition, reincision and fill at all stages of the systems life.

Cerro Torro, Chile

Outcrop work in the Cretaceous Cerro Torro formation of Chile highlight the extreme variation in grain size within a small geographic area in a channel complex (Beaubouef 2004). Channel complexes are roughly 100 feet thick, while channel complex sets are up to 800 feet thick. The contrast between grain sizes between channel and interchannel facies can range from cobbles to mud, which would create extreme heterogeneities for fluid flow in a reservoir system. Sandstone bedding is on the scale of meters, or even less, far below the resolution of traditional seismic. There is simply no way to image features of this scale in the Mad Dog. Therefore, their existence must be implied (or not) based on careful comparison of the larger elements within outcrop studies, such as this to features that are resolvable in the Mad Dog seismic volume.

CAPISTRANO FORMATION, CALIFORNIA

Perhaps one of the better-known outcrops of deep-water turbidites is the Late Miocene to Pliocene Capistrano Formation in California. This outcrop has previously been used as an analog for ancient channel systems in offshore West Africa (Stewart et al. 2008). The Miocene nested channels exposed here are on the order of less than a hundred to several hundred meters thick and exhibit abundant high-angle (10-16°) mud drapes (30 cm to 2 m) (Walker 1975). While the scale of these channels and mud drapes are orders of magnitude different from the Mad Dog channel complex, the processes proposed to be responsible for their deposition are interpreted herein to be very similar. In that process, the finer fraction of turbidity flows settle out of suspension and cap the heavier sediments. Later flows erode them away in the axis of the channel, but the drapes remain preserved in the margins (Stewart et al. 2008). Flow modeling based on the two key heterogeneous deposits (gravel lags and shale drapes) within the Capistrano Formation significantly negatively impacted recovery efficiency compared to models where these deposit types are not present.

The merging of seismic and outcrop scales involves a delicate balance between inference of features that cannot be seen and expanding known systems to scales that cannot be observed. The view of strata that is seen in seismic is an extremely simplified view of very complex systems. The key is to keep in mind that it will rarely be possible to see the whole picture, and an understanding of depositional processes and their consequences in the rock record are useful guides.

To summarize the observations in these comparative analogies:

1. Based on examples within the Amazon fan and Gulf of Guinea, overall architecture and distribution of elements is not dependent on scale within one order of magnitude.
2. Some outcrop examples of confined channels show significant variability in grain sizes (i.e., Cerro Torro, Chile; Solitary Channel, Spain). The coarser components, gravels and lags, would not be detectable in the seismic of the Mad Dog or the single well located on the confined channel margins but might be present in the channel axis.
3. Architecture within deep-water confined channels on the scale of 10 m or less, would only be able to be picked up on high frequency (65hz) seismic data.
4. Lateral and medial accretion likely occurred at various locations within the Mad Dog confined channel as bypass was active in other localities within the confined channel. There is no reason to believe that this was a vacuous space for some period of time, as we know that does not happen in subaerial river deposits. Rather the fill is a dynamic and ongoing process of deposition, reincision and fill at all stages of the systems life.

5. The processes proposed to be responsible for the deposition of clay drapes in outcrops of the Capistrano Formation, California are interpreted herein to be very similar to those we would propose to form the clay-rich intervals found in logs penetrating the Mad Dog Channel Complex.

Summary and Conclusions

A 2200 sq km 3D seismic data set and data from a single well penetration have been used to examine a large confined deep-water valley along the Sigsbee Escarpment in the Gulf of Mexico. Three bounding surfaces provided a framework within which to map 10 internal fill horizons that document lateral and medial accretion packages. The examination of the timing and extent of the valley and its fill offer insights into the reservoir architecture of these types of deposits and provide some insights into the influence that larger structural features and events might play in influencing the character of these systems. Conclusions of this study include:

- Large-scale channel-levee systems can aid in mapping across significant boundaries, such as intrusive salt bodies. Active salt provinces often have more complex geometries than simple faulted systems. The distinctive morphology and bright amplitudes associated with large channel systems are relatively easy to locate. These systems are especially useful in areas without well-constrained dating due to sparse or absent biostratigraphic data on either or both sides of the barrier.
- The distribution of elements within a large-scale deep-water channel levee system, as well as their morphology is affected by gradient and varies with proximity to the system terminus. This relationship has been established over decades in the shallower areas of the slope. A goal of this study was to move from

looking at these architectures in more proximal areas to looking at their character in more distal areas such as out in the front of the escarpment. Confined channel complexes in distal settings contain similar proximal to distal variations as those described in studies from more proximal settings. These proximal to distal zones include:

    - Proximal well developed master leveed channel complex
    - Medial confined channel complex, high angle LAPS, increased slumpling
    - Distal confined channel complex, low angle LAPS, stacked mid-channel accretionary bodies

- LAPS and MAPS can occur in close proximity to one another within the same channel complex. While MAPs develop farther downdip, and LAPs form closer to the topographic high.
- Thick shales are preserved between LAP events, primarily along channel margins. These shales would likely create baffles to flow in a reservoir setting. They are typically only preserved along channel margins because subsequent flows remove them within the channel axis.
- History of the salt sheet has important implications for history of sedimentation. It has been proposed that the southern flank of the mini-basin inflated in early Pliocene. This does not appear to be the case based on the evidence within the channel-levee complex. Linked shelf-slope sedimentation does not cease after the basal Pliocene unconformity. Sediment pathways appear to have existed until approximately 800,000 years ago, which implies a more recent uplift than

previously described. The Mad Dog outboard salt was not a significant emergent barrier to sedimentation until Middle Pleistocene time. However, it does appear that the salt sill influenced the valley fill morphology by creating proximal loading and subsidence in the valley, which responded by backstacking of medial accretion deposits. In addition, the northern V-shaped canyon has minimal levee development and more spillage in crevasses; the southern U-shaped valley has high levee development and abundant large sinuous channels. The shift in element morphology coincides with the location of the salt front, which implies that there may have been some topography related to the growing salt structure during deposition of the channel complex.

- Formation of the large channel systems coincided with the “docking” of the rafted Poseidon Minibasin. The minibasin was rafted in the early Tertiary from ~ 28 miles north to its present position. When it reached the final location above the Mad Dog Anticline, it rose slightly causing the development of a monocline. This monocline is utilized by the deep-water depositional systems to develop large bypass valleys into the ultradeep.

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